Unit - I

Chapter - 1

INTRODUCTION AND MECHANICAL ENERGY BASED PROCESSES

Syllabus : Unconventional machining Process - Need - classification - merits, demerits and applications. Abrasive Jet Machining - Water Jet Machining - Abrasive Water Jet Machining - Ultrasonic Machining. (AJM, WJM, AWJM and USM). Working Principles - equipment used - Process parameters - MRR- Applications.

1.1 Introduction

- The main work of an engineer and scientist is the development of newer methods.
- The main ideas behind such works are :
  - Economic considerations.
  - Replacement of old manufacturing methods by faster ones and more efficient ones.
  - To get high accuracy and high surface finish.
  - Use low cost material instead of costlier ones.
  - Developing new methods of machining to machine hard materials which cannot be machined by conventional or normal methods, like tungsten, uranium, tantalum stainless steel, etc.
- The use of such costly and hard to machine materials is common in tool design industries, aircraft industries, space research equipments, power plants, ammunition industries, etc.
- To meet the requirements of these industries newer methods are developed by the engineers and scientists.
- These machining methods are called as **"Non-conventional or Un-conventional or Non-traditional or Modern methods of machining"**.
- The common parameters to be taken into consideration for selecting a particular process are as follows :
  - Physical properties of work material.
  - Type of operation to be performed like cutting, hole making, etc.
  - Shape and size required to be produced.
  - Process capabilities i.e. expected tolerance, power requirement, Metal Removal Rate (MRR), surface finish, etc.
  - Economy of the process.
  - Physical properties of workpiece material.

Limitations of conventional manufacturing process

i) Conventional manufacturing process are difficult to machine the harder or newly developed materials like carbides, ceramics, High Strength Temperature Resistance (HSTR) alloys etc.,

ii) The surface finish level is not quite high.

iii) High tolerance or close tolerance cannot be achieved.

iv) Difficult to obtain complex shapes.

v) Automated data transmission is not possible.

vi) Mass production at high production rate with high accuracy is not possible.

vii) The generation of shallow holes, non-circular micro sized holes are not possible.

viii) High wastage of material.

ix) The degree of accuracy and precision are not in best position.

x) A large number of holes in a single workpiece with better quality is quite difficult.

xi) Unconventional machining process not so effective on soft materials like aluminium because accuracy cannot be maintained due to more material removal rate.

1.1.1 Characteristics of Non Conventional Processes

Non Traditional Machining (NTM) processes are characterized as follows :

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

1.1.2 Need for Development of Un-Conventional Processes

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

1. Technologically advanced industries like aerospace, nuclear power, ,wafer fabrication, automobiles has ever increasing use of High –strength temperature resistant (HSTR) alloys (having high strength to weight ratio) and other difficult to machine materials like titanium, SST,nimonics, ceramics and semiconductors. It is no longer possible to use conventional process to machine these alloys.
2. Production and processing parts of complicated shapes (in HSTR and other hard to machine alloys) is difficult , time consuming an uneconomical by conventional methods of machining.
3. Innovative geometric design of products and components made of new exotic materials with desired tolerance , surface finish cannot be produced economically by conventional machining.
4. The following examples are provided where NTM processes are preferred over the conventional machining process :
   - Intricate shaped blind hole – e.g. square hole of 15 mm × 15 mm with a depth of 30 mm with a tolerance of ± 100 microns.
   - Difficult to machine material – e.g. Inconel, ti-alloys or carbides, ceramics, composites , HSTR alloys, satellites etc.,
   - Low stress grinding – Electrochemical grinding is preferred as compared to conventional grinding.
   - Deep hole with small hole diameter – e.g. φ 1.5 mm hole with $l/d = 20$
   - Machining of composites.

Definition :

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

1.2 Comparison between Conventional and Unconventional Machining Processes

S.No	Conventional Process	Un Conventional Process
1.	The cutting tool and work piece are always in physical contact with relative motion with each other, which results in friction and tool wear.	There is no physical contact between the tool and work piece, In some nontraditional process tool wear exists.

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

1.3 Classification of Advanced Machining Processes

The different non-conventional machining methods are generally classified using the following criteria :

(1) According to the type of energy used : Mechanical, electro-chemical or electrothermal, chemical, etc.

(2) According to the energy source : Pneumatic or hydraulic pressure, mechanical pressure, high current or voltage, etc.

(3) According to the medium for energy transfer : High velocity particles, physical contact, electrolyte, hot gases, electrons, radiation, etc.

(4) According to the metal removal mechanism : Erosion, spark erosion, shear, vaporisation, etc.

1.3.1 Process Selection

The common parameters to be taken into consideration for selecting a particular process are as follows :

(i) Physical parameters of unconventional machining methods

Table 1.1 : Physical parameters in non-conventional machining methods

Parameters	Unconventional machining methods						
	EDM	**EBM**	**PAM**	**LBM**	**USM**	**AJM**	**ECM**
Voltage (Vts)	100 to 300	150×10^3	100	4.5×10^3	220	220	10 to 30
Current (Amp)	50	0.001	500	2	12	1	10,000
Power (kW)	2.7	0.15	50	-	2.4	0.22	100
Gap (mm)	0.025	100	7.5	150	0.25	0.75	0.2
Medium	Dielectric fluid	Vacuum	Hydrogen or argon	Air	Abrassive in water or paraffin	Abrasive in gas	Electrolyte

(ii) Shape and size required to be produced

- The different non-conventional machining methods have some special shape producing capability as follows :
  - Standard hole drilling : EDM and USM
  - Fine hole drilling and contour machining : ECM
  - Clean, rapid cuts and profiles : PAM
  - Micro-machining and drilling : LBM and EBM

(iii) Process capability

- Out of all the non-conventional machining methods, EDM has the lowest specific power requirement and it can achieve sufficient accuracy whereas ECM has the highest MRR (Metal Removal Rate).
- USM and AJM have low MRR and combined with tool wear whereas LBM and EBM have high penetration rates with low MRR.

(iv) Process economy

- The process economy of various non-conventional machining methods is given in the following Table 1.2.

Table 1.2 : Process economy

Process	Capital cost	Power requirement	Efficiency
EDM	Medium	Low	High
EBM	High	Low	Very high
PAM	Very low	Very low	Very low
LBM	Medium	Very Low	Very high
USM	Low	Low	High
AJM	Very low	Low	High
ECM	Very high	Medium	Low
Conventional method	Low	Low	Very low

(v) Physical properties of workpiece material

(vi) Type of operation to be performed

1.3.2 Commonly Used Advanced Machining Processes

(1) Electro-Discharge Machining (EDM)

(2) Wire-cut Electro-Discharge Machining (W-EDM)

(3) Electron Beam Machining (EBM)

(4) Plasma Arc Machining (PAM)

(5) Laser Beam Machining (LBM)

(6) Ultra Sonic Machining (USM)

(7) Abrasive Jet Machining (AJM)

(8) Electro-Chemical Machining (ECM)

(9) Chemical Machining (CM)

(10) Electro-Chemical Grinding (ECG)

(11) Water-Jet Machining (WJM)

(12) Ion-Beam Machining (IBM)

1.4 Classification of Unconventional Machining Process

Unconventional machining process are classified as follows :

a) Based on the type of energy required to shape the material

i. Thermal energy method

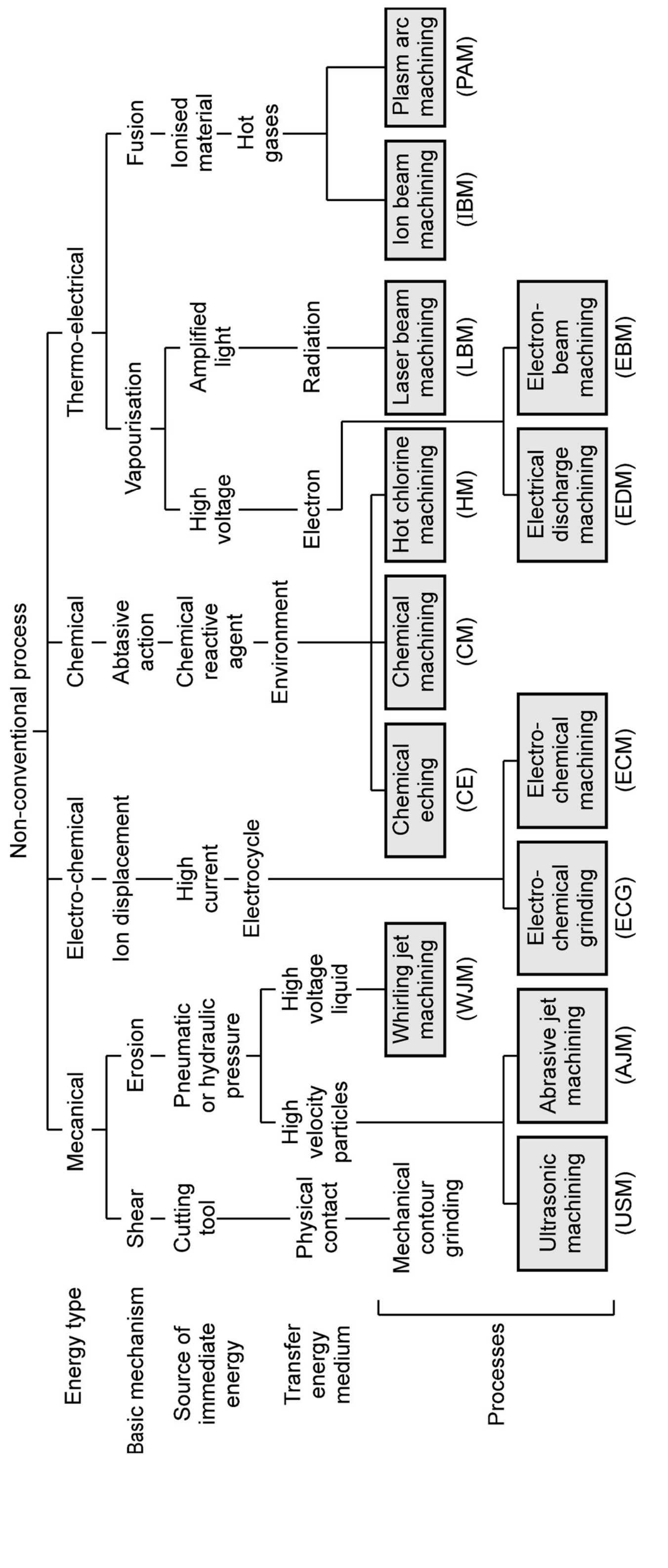
ii. Electrical energy method

iii. Electro Chemical energy method

iv. Chemical energy method

v. Mechanical energy method.

Table 1.3 : Classification of non-conventional processes



b) Based on the mechanism involved in the process

i. Erosion
ii. Ionic dissolution
iii. Vaporisation

c) Source of energy required for material removal

i. Hydrostatic pressure
ii. High current density
iii. High voltage
iv. Ionised material

d) Medium of transfer of energies

i. High voltage particles
ii. Electrolyte
iii. Electron
iv. Hot gases

Abreviations Used :

1. AJM - Abrasive Jet Machining
2. USM - Ultrasonic Machining
3. WJM - Water Jet Machining
4. AWJM - Abrasive Water Jet Machining
5. ECM - Electro Chemical Machining
6. ECG - Electro Chemical Grinding
7. EJD - Electro Jet Drilling
8. EDM - Electro Discharge Machining
9. LJM - Laser Jet Machining
10. EBM - Electron beam Machining
11. PAM - Plasma Arc Machining
12. CHM - Chemical Milling
13. PCM - Photo Chemical Milling

1.4.1 Selection of Process

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

i) Physical parameters of the process

ii) Shape to be machined

iii) Process capability

iv) Economics of the processes

1.5 Physical Parameters of the Process

EBM and LBM require high voltages and require careful handling of equipment. EDM and USM require medium power. EBM can be used in vacuum and PAM uses oxygen and hydrogen gas.

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

1.5.1 Shapes Cutting Capablity

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

Application	Process well suited
Producing micro holes	LBM
Producing small holes	EBM
For deep holes (L/D >20) and contour machining	ECM
For shallow holes	USM and EDM
For precision through cavities in workpieces	USM and EDM
For Honing	ECM
For etching small portions	ECM and EDM
For grinding	AJM and EDM
For deburring	USM and AJM
For threading	EDM
For clean, rapid cuts and profiles	PAM
For shallow pocketing	AJM

Capability to shape

Process	Capability to									
	Contouring a surface	Micro Drill	Drill		Cavity sinking		Pocketing Operation		Through cutting	
			L/D <20	L/D >20	Accurate Operation	Standard Operation	Shallow Pocketing	Deep pocketing	Shallow cutting	Deep cutting
USM	P	-	G	P	G	G	P	P	P	-
AJM	-	-	F	P	P	F	-	-	G	-
ECM	G	-	G	G	F	G	G	G	G	G
CHM	-	F	-	-	P	F	G	P	G	-
EDM	F	-	G	F	G	G	G	G	P	-
EBM	-	F	F	P	P	P	-	-	G	F
LBM	-	G	F	P	P	P	-	-	G	F
PAM	-	-	F	-	P	P	-	-	G	G

P - Poor , F- Fair, G- Good

1.5.2 Process Capability

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

Process	Material Removal rate	Surface finish	Accuracy		Specific power	
			L/D <20	L/D >20	Accurate Operation	Standard Operation
USM	P	-	G	P	G	G
AJM	-	-	F	P	P	F
ECM	G	-	G	G	F	G
CHM	-	F	-	-	P	F
EDM	F	-	G	F	G	G
EBM	-	F	F	P	P	P
LBM	-	G	F	P	P	P
PAM	-	-	F	-	P	P

1.5.3 Applicability to Material

Process	Metals and alloys					Non-Metals		
	Aluminum	Steel	Super Alloys	Titanium	Refractory Material	Ceramics	Plastics	Glass
USM	P	F	P	F	G	G	F	G
AJM	F	F	G	F	G	G	F	G
ECM	F	G	G	F	F	-	-	-
CHM	G	G	F	F	P	P	P	P
EDM	F	G	G	G	G	-	-	-
EBM	F	F	F	F	G	G	F	F

LBM	F	F	F	F	P	G	F	F
PAM	G	G	G	F	P	-	P	-

P - Poor , F- Fair, G- Good

1.5.4 Machining Characteristics

Process	A	B	C	D	E
USM	300	7.5	0.2-0.5	25	2,400
AJM	0.8	50	0.5-1.2	2.5	250
ECM	15,000	50	0.1-2.5	5	1 Lakh
CHM	15	50	0.5-2.5	5	-
EDM	800	15	0.2-1.2	125	2700
EBM	1.6	25	0.5-2.5	250	150(Avg) 2 (Peak)
LBM	0.1	25	0.5-1.2	125	2 (Avg.) 200 (Peak)
PAM	75,000	125	Rough	500	50,000

A – Metal Removal rate obtained (in mm^3/min)

B – Tolerance maintained (in micron)

C – Surface finish obtained (in micron)

D – Depth of surface damaged (in micron)

E – Power required for machining (in watts)

1.5.5 Effects on Equipment and Cooling

Process	Tool wear ratio	Machining medium contamination	Safety	Toxity
USM	10	B	A	A
AJM	-	B	B	B
ECM	-	C	B	A

CHM	-	C	B	A
EDM	6.6	B	B	B
EBM	-	B	B	A
LBM	-	A	B	A
PAM	-	A	A	A

A - No Problem , B - Normal Problem, C - Critical Problem

$$\text{Tool wear ratio} = \frac{\text{Volume of work material removed}}{\text{Volume of tool electrode removed}}$$

1.6 Hybrid Process

- To increase the capabilities of the machining processes, two or more than two machining processes are combined to take advantage of each and every processes.
- For example : A conventional grinding produces good surface finish and low tolerances but the components are associated with burrs, heat affected zone and residual stresses. But, electrochemically machined components do not have such defects. Hence, a hybrid process known as electrochemically grinding (ECG) has been developed.
- Similarly, other hybrid processes like electrochemical spark machining, electrochemical arc machining, electro-discharge abrasive, etc. have been developed.
- This chapter includes the following processes :

i) Abrasive Flow Finishing (AFF)
ii) Magnetic Abrasive Finishing (MAF)
iii) Abrasive Water Jet Machining (AWJM)
iv) Wire Electric Discharge Machining (W - EDM)
v) Electrochemical Grinding (ECG)
vi) Electrochemical De-burring (ECD)
vii) Shaped Tube Electrolytic Machining (STEM)
viii) Electrolyte Jet Machining (EJM)
ix) Electrolytic in-Process Dressing (ELPD)
x) Ultrasonic assisted EDM (U - EDM)
xi) Rotary EDM
xii) Electrochemical Discharge Machining (ECDM)
xiii) Laser surfac

1.7 General Characteristics of Unconventional Machining Process

Process	Characteristics	Process Parameters, Typical MRR or cutting speed
Chemical Machining (CHM)	➢ Shallow removal (upto 12 mm) on large flat or curved surfaces; ➢ Blanking of thin sheets; ➢ Low tooling and equipment cost; ➢ Suitable for low production runs.	0.025 - 0.1 mm/min
Electrochemical Machining (ECM)	➢ Complex shapes with deep cavities; ➢ High MRR; ➢ Expensive tooling and equipment; ➢ High power consumption; ➢ Medium to high production quantity.	Voltage – 5 to 25 DC- 1.5 to 8 A/mm^2 2.5 – 12 mm/min Depending on current density
Electrochemical Grinding (ECG)	➢ Cutting off and sharpening hard materials such as tungsten carbide tools; ➢ Also used as a honing process; ➢ Higher material removal rate than grinding.	A: 1-3 A/mm^2 Typically 1500 mm^3 / min per 1000 A
Electrical Discharge Machining (EDM)	➢ Shaping and cutting complex parts made of hard materials; ➢ Some surface damage may result; ➢ Also used for cutting and grinding; ➢ Versatile expensive tooling and equipment;	V: 50-380 A : 0.1-500 Typically 300 mm^3 /min.
Wire EDM	➢ Contour cutting of flat or curved surfaces; ➢ Expensive equipment.	Varies with workpiece material and its thickness.

Laser Beam Machining (LBM)	➢ Cutting and hole making in thin materials ➢ Heat Affected Zone (HAZ)’ ➢ Does not require vacuum ➢ Expensive equipment ➢ Consumes much energy ➢ Extreme caution required in use	0.5 – 7.5 m/min
Abrasive Water Jet Machining (AWJM)	➢ Single and multilayer cutting f metallic and non- metallic materials	Upto 7.5 m/min.
Electron Beam Machining (EBM)	➢ Cutting and hole making on thin materials ➢ Very small holes and slots. ➢ HAZ ➢ Requires vacuum ➢ Expensive equipment	1-2 mm^3/min.
Water Jet Machining (WJM)	➢ Cutting all types of non-metallic materials to 25 mm. and greater in thickness. ➢ Suitable for contour cutting of flexible materials ➢ No thermal damage ➢ Environmentally safe process.	Varies considerably with workpiece material.
Abrasive Jet Machining (AJM)	➢ Cutting, slotting, deburring, flash removal, etching and cleaning of metallic and non-metallic materials. ➢ Tends to round off sharp edges ➢ Some hazard because of airborne particulates. (Airborne particulate matter, which includes dust, dirt, soot, smoke, and liquid droplets emitted into the air, is small enough to be suspended in the atmosphere)	Varies considerably with workpiece material.

1.8 Comparison of Various Unconventional Machining Process

S.No	Process parameters	EDM	ECM	EBM	LBM	PAM	USM	AJM	WJM
1	Metal Removal Technique	By using powerful electric spark	Based on faraday's Laws of electrolysis	By using high velocity beam of electrons	By using high intensity of laser beam	Heating, melting and vaporizing by using plasma	Slurry of small abrasive particles is forced against workpiece by means of vibrating tool	By using high stream of abrasive particles mixed with air	By using high velocity of water jet
2	Work material	Electrically conductive metals and alloys	Difficult to machine Electrically conductive materials	All materials	All materials except those having high thermal conductivity and high reflectivity	All materials which conduct electricity	Tungsten Carbide, Glass, Quartz, ceramics, etc,	Hard and brittle materials like glass, quartz, ceramics, etc	Soft and non-metallic materi als like wood, plastic, paper-board etc
3	Tool material	Copper, yellow, alloy of zinc, copper, tungsten etc.,	Copper, brass, titanium, copper tungsten, stainless steel etc.,	Electron Beam	Laser Beam	Plasma	Low carbon steel, stainless steels	Abrasives like aluminium oxide, silicon carbide, glass powder etc.,	Water jet
4	Metal removal (mm^3 / sec)	15 to 80	27	15 to 40	0.10	2500	14	0.014	0.6
5	Surface finish in µm	0.25	0.2 to 0.8	0.4 to 6	0.4 to 6	Rough	0.2 to 0.7	0.5 to 1.2	0.5 to 0.8
6	Power requirement	Low	Medium	Low	Very low	Very low	Low	Low	High
7	Capital cost	Medium	High	High	High	Low	High	Very low	High
8	Efficiency	High	Low	Very high	Very high	Very low	High	High	High
9	Applications	Production of complicated and irregular shaped profiles and re sharpening of cutting tools	Machining hard materials and complex shaped parts	Micro machining operations on thin materials like drilling, slotting, scribing etc.,	Drilling micro holes (upto 250 µm) and cutting very narrow slots	Profile cutting of stainless steel, monel and super alloy plates	Efficiently applied to machine glass, ceramics, tungsten etc.,	Intricate hole shapes in hard and brittle materials	Machining non-metallic materials
10	Limitations	Not suitable for non-conducting materials	Not suitable for non-conducting materials	Not suitable for large work pieces, necessity of vacuum	Taper of 0.05 mm when work thickness is more than 0.25 mm	Low accuracy	Low metal removal rate, high rate of tool wear	Low MRR, low accuracy	Difficult to machine hard materials

1.9 Mechanical Energy Based Process

The mechanical energy based processes are as follows :

- Abrasive Jet Machining
- Water Jet Machining
- Abrasive Water Jet Machining

1.10 Abrasive Jet Machining (AJM)

- AJM uses a stream of fine grained abrasives (of size 10 to 40 microns) mixed with air or some other carrier gas at high pressure.
- This stream is directed on the work surface by using a suitable nozzle.
- The velocity of carrier gas or air is upto 200 to 400 m/sec.
- Due to this high speed, impact on the work surface erosion takes place by abrasive particles and metal removes from the workpiece.
- AJM differs from the conventional sand blasting process in the way that the abrasive is much finer and the effective control over the process parameters and cutting action. This process is chiefly employed to cut hard and brittle materials which are thin, sensitive to heat and have a tendency to break away or chip off easily.

Construction

- Fig. 1.1 shows typical setup for Abrasive Jet Machining, which consists of a 'mixing chamber' in which fine grained abrasive particles are filled through a holding device like a 'hopper'.
- This mixing chamber vibrates (upto 50 cycles/sec) and amplitude of these vibrations controls the flow of abrasive particles. To control the amplitude of vibration, regulator is placed in the system.
- Compressed air or high pressure gas is supplied to the mixing chamber through a pipe line, which carries a pressure gauge to control its pressure.
- These particles mix in the stream of gas, *travel via a* hose and *pass through a nozzle. This* stream of mixture of gas and abrasive particles is called as **Abrasive Jet.**

Process

- In abrasive jet machining abrasive particles are made to impinge on work material at high velocity. Jet of abrasive particles is carried by carrier gas or air.
- The high velocity stream of abrasives is generated by converting pressure energy of carrier gas or air to its Kinetic energy and hence high velocity jet.

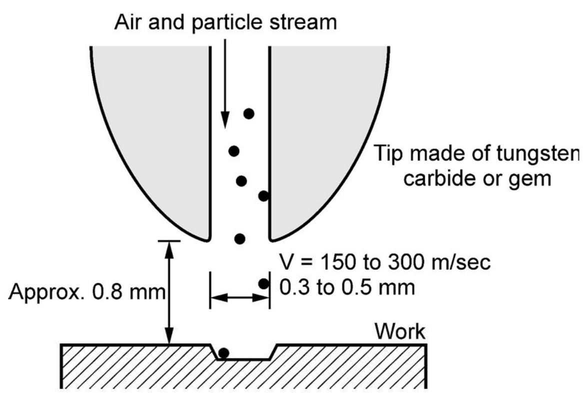


Fig. 1.1

- Nozzles 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.

Working

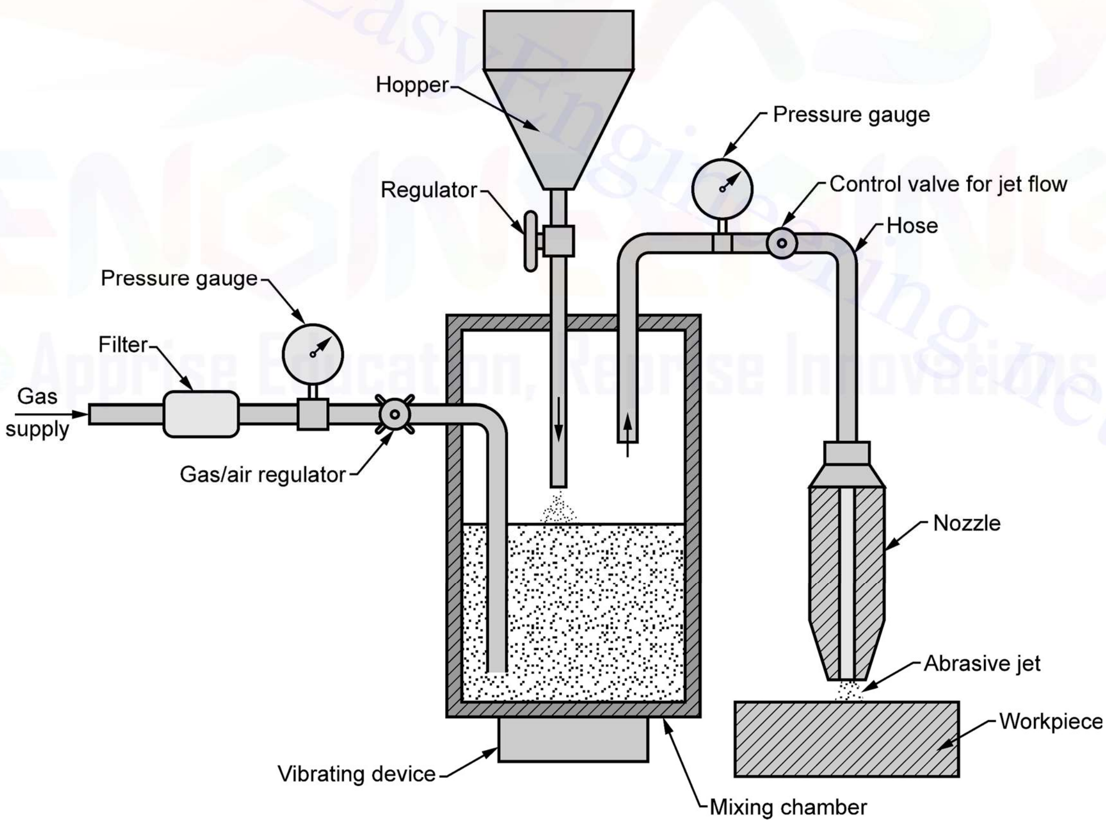


Fig. 1.2 Schematic diagram of AJM

- Through hopper, fine grained abrasive powder is filled in a mixing chamber.
- The gas or air is supplied under pressure into the chamber; the pressure of gas varies from 2 to 8 kg/cm^2.
- The gas is supplied through the pipeline which carries a pressure gauge and regulator to control the flow.
- This mixture of high pressure gas and compressed air is passed through a nozzle on the the surface of workpiece, and due to high speed mixture erosion is caused and metal removal takes place.

Equipment :

Abrasive jet machining consists of

1. Gas propulsion system	2. Abrasive feeder
3. Machining chamber	4. AJM nozzle
5. Abrasives	

1. Gas Propulsion System

- It 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, 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.

2. 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 a 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.

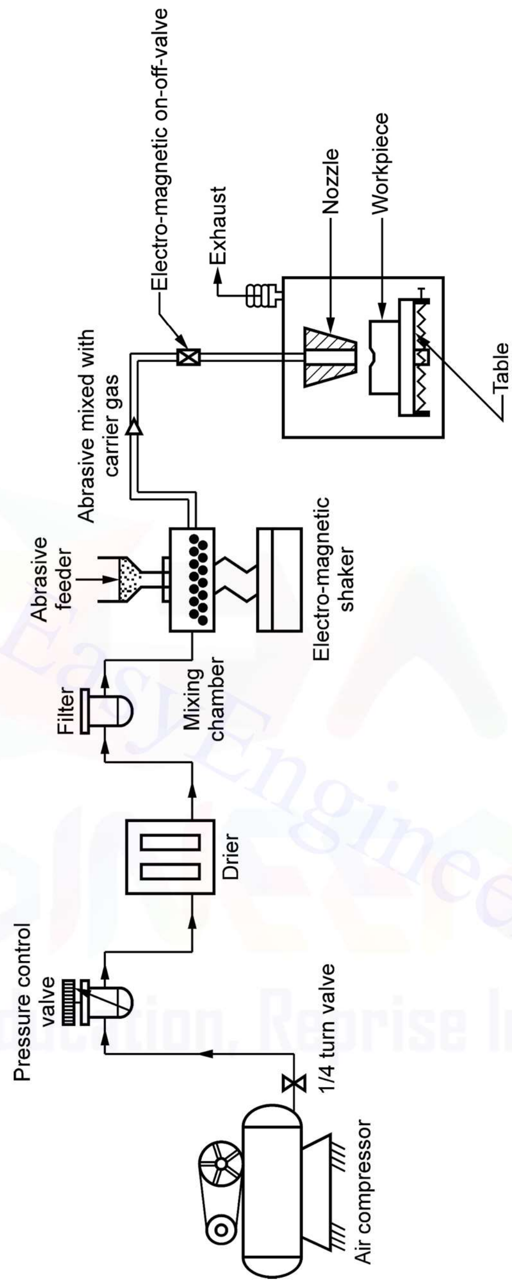


Fig. 1.3

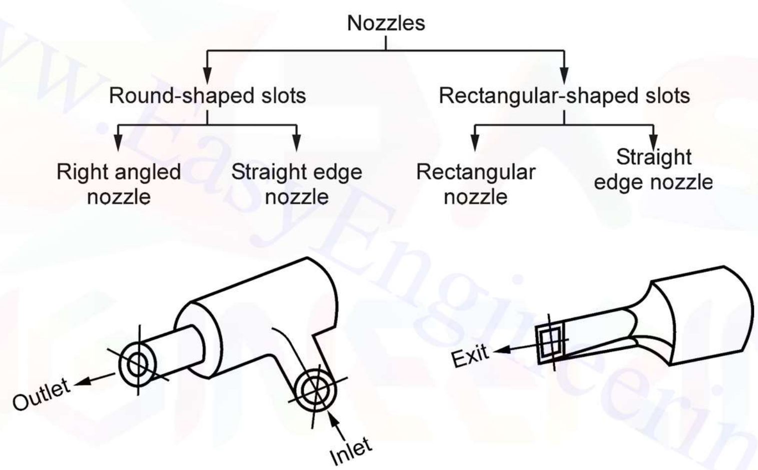
3. Machining chamber

- 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.

4. 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.



(a) Right-angled, round shaped nozzle **(b) Straight edge rectangular shaped nozzle**

Fig. 1.4

Nozzle material	Round shape nozzle diameter, mm	Rectangular shape slot dimension, mm	Life of nozzle, hours
Tungstern carbide (WC)	0.2 to 1.0	0.075×0.5 to 0.15×2.5	12 to 30
Sapphire	0.2 to 0.8	—	300

5. 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 1.27 mm	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

1.10.1 Mechanism of Material Removal in AJM

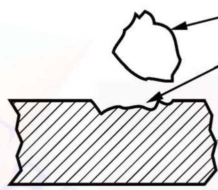


Fig. 1.5 Mechanism of metal removal in abrasive jet machining

When the abrasive particles impinge on the work piece or work surface at a high velocity, the impact of the particles causes brittle fracture at the places where the particles hit and the following gas or air varies away the dislodges small workpiece particles.(wear partilces). The mathematical model of the material removal rate is based on the following assumptions.

1. The abrasive particles are considered to be rigid and spherical bodies of equal diameter to the average grit size.
2. The material removed is equal to the volume of indentation in the case of a ductile work material. It is equal to the chord length of indentation and is hemispherical in shape in the case of brittle material.

$$\text{MRR for brittle material} = 1.04[MV^{3/2} / \rho^{1/4} H^{3/4}]$$

$$\text{MRR for ductile material} = 0.5[MV^{2}/H]$$

Where, M = The abrasive mass flow rate

V = The impact velocity

ρ = The density of the particle

H = The material hardness of the work piece.

- From the equation, Velocity plays a dominant role compared to the mass flow rate on MRR. Under low velocity conditions ductile materials show lower MRR.

- For successful utilization of AJM process, it is necessary to analyze the following process criteria.
  1. Material removal rate
  2. Geometry and surface finish of work piece
  3. Wear rate of the nozzle

However, process criteria are generally influenced by the process parameters as enumerated below :

- **Abrasives**
  - a) Material – Al_2O_3, SiC, glass beads, crushed glass, sodium bi carbonate
  - b) shape – irregular/regular
  - c) Size – 10 to 50 microns
  - d) Mass flow – 2-20 gm/min

- **Carrier Gas**
  - a) 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**
  - a) Velocity - 100 to 300 m/s
  - b) Mixing ratio – Volume flow rate of abrasives/Volume flow rate of gas c) Stand off distance – SOD - 0.5 to 15 mm.
  - d) Impingement angle – 60 to 90 deg.

- **Nozzle**
  - a) Material – WC/Sapphire
  - b) Diameter – 0.2 to 0.8 mm
  - c) Life – 300 hours for sapphire, 20 to 30 hours for WC

Process capability

1. Material removal rate – 0.015 cm^3/min
2. Narrow slots – 0.12 to 0.25 mm ± 0.12 mm
3. Surface finish -0.25 micron to 1.25 micron
4. Sharp radius up to 0.2 mm is possible

5. Steel up to 1.5 mm, Glass up to 6.3 mm is possible to cut
6. Machining of thin sectioned hard and brittle materials is possible.

1.10.2 Parameters in AJM

The parameters which affect MRR and accuracy of the machining process are :

1. Carrier gas :

- A carrier gas used in the process must not flare excessively when discharged from the nozzle into the atmosphere. A gas used should be non-toxic, cheap, easily available and capable of being dried easily.
- Commonly used gases are air, nitrogen and carbon di-oxide.
- If an air compressor is used proper line filters must be fixed to avoid water or oil contamination of the abrasive powders. Since these contamination presents clogging problem in the nozzle.
- Oxygen should never be used due to hazardous problem.

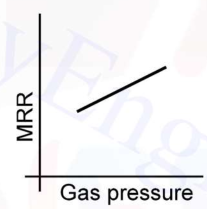


Fig. 1.6

2. Types of abrasives :

- The abrasive used in the process should have a sharp and irregular shape and should have excellent flow characteristic.
- Commonly used abrasives are aluminium oxide and silicon carbide for general machining and grooving whereas sodium bi-carbonate for fine finishing and dolomite for etching and light cleaning purpose.
- **Reuse of abrasives is not recommended** since the cutting ability of abrasive decrease after the usage and also the contamination of wear materials clogging the nozzle and the cutting unit orifices.
- It is important to note that sodium bicarbonate is hygroscopic and will absorb moisture if heated above 49° thus rendering it useless, if allowed to become moist.

3. Jet velocity :

- The kinetic velocity of the abrasive jet is utilised for metal removal by erosion.

- The velocity is a function of nozzle pressure, nozzle design and abrasive grain size.
- Higher nozzle pressure results in greater MRR. Also, higher grain size produces higher MRR. The inside diameter of the nozzle is about 0.04 mm.

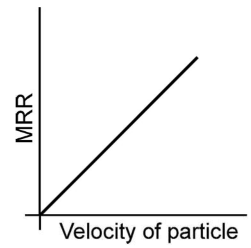


Fig. 1.7

4. Stand - Off Distance (SOD) or Nozzle Tip Distance (NTD) :

- It is the distance between the face of the nozzle and working surface of the workpiece to be machined.
- Generally, it is kept about 0.7 mm to 1.0 mm.
- The shape and size of cavity produced as well as the surface of the workpiece is affected by NTD.
- If NTD increases the velocity of abrasive particles striking on the workpiece also increases, hence MRR also increases.
- Initially MRR increases with NTD after which it remains unchanged for a certain NTD and then falls gradually. Fig. 1.8 shows effect of NTD on MRR

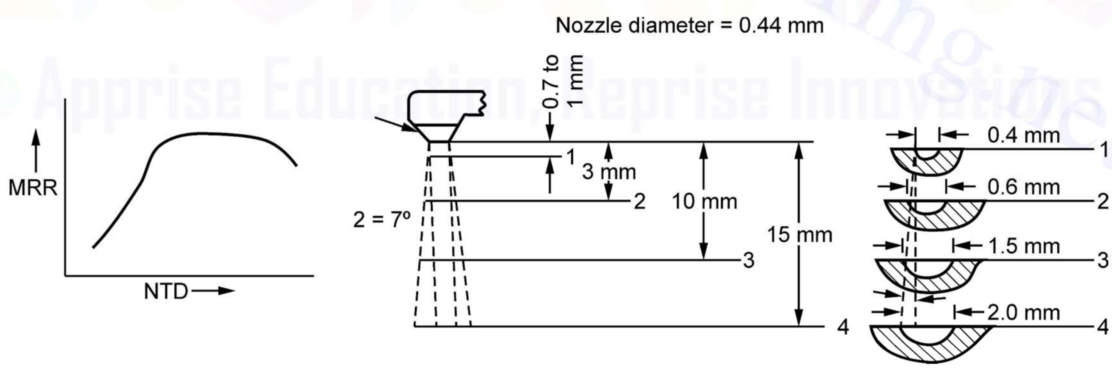


Fig. 1.8

5. Size of the abrasive grain

- The MRR in the AJM process depends on the size of the abrasive grain.
- The abrasives are available in many sizes ranging from 10μ to 50 μ. But best cutting results have been obtained if the size of the bulk ranges from 15 μ to 40 μ

- **Finer grains** are less irregular in shape and possess lesser cutting ability. They are used for polishing, fine deburring and cleaning operations.
- **Too fine powder** may tend to cake in the abrasive storage tank and hence reduce the rate of flow and affects the MRR.
- **Over size particles** also affect the MRR by plugging the orifice and reduce the velocity of the jet by means of its weight.
- **Coarse grains** are normally recommended for cutting and peening operations.

6. Effect of mixing ratio on MRR

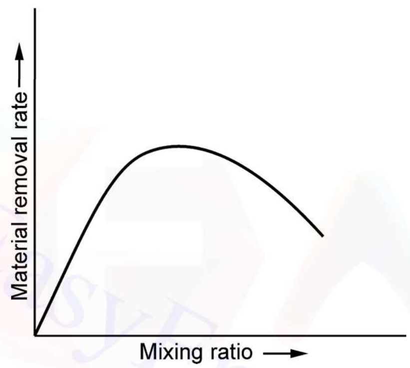


Fig. 1.9

- Increased mass flow rate of abrasive will result in a decreased velocity of fluid and will thereby decreases 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

$$\text{Mixing ratio (M)} = \frac{\text{Volume flow rate of abrasives per unit time}}{\text{Volume flow rate of carrier gas per unit time}}$$

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

- A large value of M results in higher rate of material removal up to a certain limit and then it gets reduced because a large abrasive flow rate decreases the jet velocity which is responsible for causing the impact of the abrasive on to the work piece material.
- Also it presents the problem of clogging the nozzle. Thus for a given condition there is an optimum mixing ratio that results in a maximum MRR. But when the abrasive mass flow rate increases the MRR also increases.

7. Work Piece Material

- The AJM process is best suited for machining hard, brittle and heat sensitive metals, alloys and non-metallic materials like Quartz, Germanium, Silicon, Glass, Ceramics, Mica and refractory materials of thin sections.

8. Shape of Cut

- It is not possible to machine or cut parts with sharp corners because of stray cutting.

9. Nozzle Design

- The nozzle has to withstand the corrosive action of abrasive particles and must be made of material which offers high resistance to wear.
- The nozzle is normally made of tungsten carbide or sapphire.
- The life of the nozzle is ascertain. A tungsten carbide nozzle lasts between 12 hours and 30 hours.
- A sapphire nozzle lasts around 300 hrs. Operation when used with in 27 m abrasive powder.
- Nozzles are made with an external taper to minimize the secondary effects.

10. Accuracy and surface finish

- The control of the various parameters results in a tolerance in the region of ±0.05 mm
- Normal production using AJM technique ends up in an accuracy of ±0.1 mm
- The corner radius obtained can be limited to 0.1 mm.
- Taper is around 0.05 mm per 10 mm penetration.
- Slots as narrow as 0.12 to 0.25 mm can be produced.
- The surface finish ranges from 0.4 to 1.2 mm in most of the applications.

Advantages of AJM

- Brittle materials of thin sections can be easily machined.
- No direct contact between the tool and workpiece, hence less damage to the workpiece surface.
- Holes of any shape and intricate cavities can be machined.
- Initial investment is low as compared to other methods.
- Power consumption is low.

Disadvantages of AJM

- AJM is suitable only for brittle materials, as MRR is high for brittle materials.
- Machining accuracy obtained is poor i.e. upto ± 50 microns.
- MRR is low i.e. upto 0.05 cm^3/hr.

- There is always a chance of abrasive particles getting inserted in the work material, hence cleaning needs to be done after machining.
- The used abrasive powder can not be reused.
- Process tends to pollute the environment.

Applications of AJM

- The process is best suited for machining brittle and heat sensitive materials like glass, quartz, sapphire, ceramics, etc.
- It is used for drilling holes, cutting slots, cleaning hard surfaces, deburring, polishing, etc.
- It is used for producing high quality surface.
- It is used for reproducing designs on a glass surface with the help of masks made of rubber, copper, etc.
- Used for etching markings on glass cylinders.
- Used for frosting interior surfaces of glass tubes.
- Used for cutting thin sectioned fragile components made of glass, refractories, ceramics, mica, etc.
- Used for aperture drilling for electronic microscopes

1.10.3 Metal Removal Rate (MRR) in AJM

- The material removal rate in abrasive set machining is given by,

$$\text{M.R.R.} = K \cdot N \cdot d^3 \cdot v^{\left(\frac{3}{2}\right)} \cdot \left(\frac{\rho}{12H}\right)^{\left(\frac{3}{2}\right)} \quad \dots (1.1)$$

where,
K = Constant
N = Number of abrasive particles impacting per unit time.
d = Mean diameter of abrasive particles.
v = Abrasive particles velocity
ρ − Density of abrasive particle
H = Hardness of work material

1.11 Abrasive Water Jet Machining (AWJM)

History

- Dr. Franz in 1950's first studied UHP (Ultra High –Pressure) water cutting for forestry and wood cutting (pure WJ) 1979 Dr. Mohamed Hashish added abrasive particles to increase cutting force and ability to cut hard materials including steel, glass and concrete (abrasive WJ)

- First commercial use was in automotive industry to cut glass in 1983
- Soon after, adopted by aerospace industry for cutting high-strength materials like Inconel, stainless steel and titanium as well as composites like carbon fiber.
- We know that, Abrasive Jet Machining (AJM), Abrasive Flow Finishing (AFF) and Ultrasonic Machining (USM) are the processes which make use of abrasives for machining of materials.
- In case of AJM, air driven abrasive jet strikes the workpiece and removes the material whereas in USM abrasive grains in liquid slurry strike the liquid surface and cut the material at low MRR.
- Now - a - days a hybrid process called abrasive Water Jet Machining or Cutting (AWJM or AWJC) is used which makes use of abrasives with water jet for machining.
- This process is similar to AJM except that, in this case water is used as a carrier fluid instead of gas.
- This process is mainly suitable for electrically non -conductive and difficult to machine materials more rapidly and efficiently than the other processes.

Definition

- Abrasive water jet machining is a mechanical energy based material removal process in which abrasives are mixed with water to form the abrasive slurry.
- It is a material removal process where the material is removed or machined by the impact erosion of the high velocity stream of water and abrasive mixture which is focused on to the work piece.
- This process is similar to abrasive jet machining except that the water is used as a carrier medium instead of dry air.

Working Principle

- During the process, a jet of water and a stream of abrasives coming from two different directions, mix up and flows through the abrasive jet nozzle. Refer Fig. 1.10.
- Because of nozzle, velocity of the abrasive rises rapidly.
- Thus, a high velocity stream of mixture of abrasives and water impinges on the surface of workpiece and removes material.
- According to the material of workpiece, the removal of material may occur due to erosion, shear or due to rapidly change in localized stress fields.

- This process is used for cutting, drilling and cleaning of hard materials. It is capable to cut ceramics, composites, rocks, metals, etc.
- The pressure at which water jet operates is about 400 MPa and jet velocity is about 900 m/s.
- The commonly used abrasives in this process are silica, garnet and silicon carbide. For hard materials, hard type of abrasive is used.

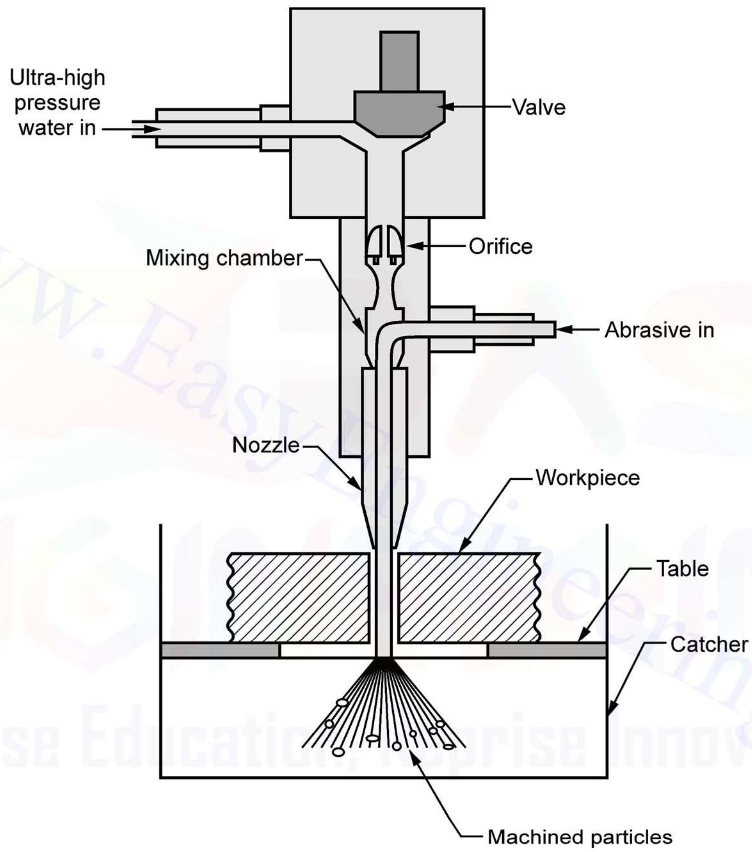


Fig. 1.10 : Working principle of AWJM

- The set-up of AWJM consists of four important elements as follows :

i) Pumping System	ii) Abrasive Feed System
iii) Abrasive Water Jet Nozzle	iv) Catcher

i) Pumping system

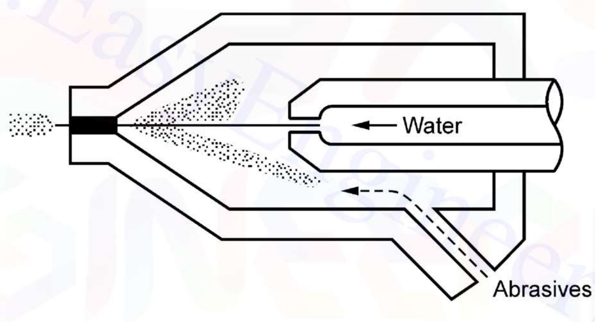
- It produces high velocity water jet by pressurizing water with the help of intensifier.
- For this purpose a high pressure motor is also required.

ii) Abrasive feed system

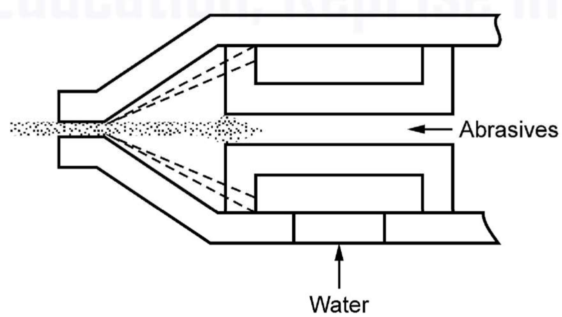
- This system delivers a controlled flow of abrasive particles to the jet nozzle. It delivers a stream of dry abrasives to the nozzle.
- The flow of water jet in a mixing chamber or tube is responsible to create enough suction for the flow of the abrasives.
- The rate of flow of abrasives can be adjusted by changing the size of the control orifice.

iii) Abrasive water jet nozzle

- This nozzle performs mixing of abrasive jet and water, and forms a high velocity water abrasive jet.
- It gives a coherent and focused abrasive stream at exit of nozzle. This nozzle is made of hard materials like sapphire, tungsten carbide or boron carbide.
- The abrasive water jet nozzle may be single jet side feed type or multiple jet central feed type. Refer Fig. 1.11.



(a) Single jet single feed nozzle



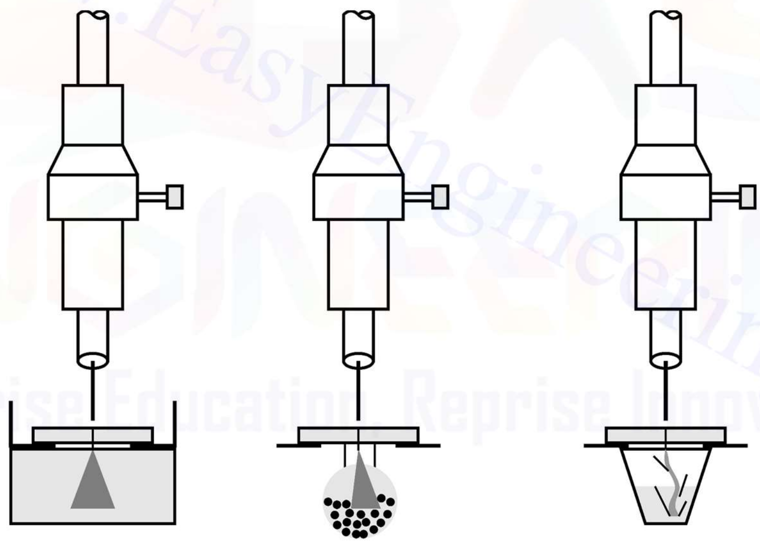
(b) Multiple jet central feed nozzle

Fig. 1.11 Abrasive water jet nozzle

- In a single jet side feed nozzle, the abrasives fed from the side and mix with water jet in the mixing chamber. These nozzles are less costly, simple but less efficient.
- In a multiple jet central feed nozzle, a centrally located abrasive feed system is surrounded by multiple water jets. It gives higher nozzle life and better mixing of abrasives and water jet.

iv) Catcher

- Catcher is a long narrow tube placed under the point of cut to capture the used jet.
- It is used when the nozzle is stationary and the workpiece moves.
- When the workpiece is stationary and the nozzle moves, water filled settling tank is provided below the workpiece.
- "Catcher" is used to absorb the residual energy of the AWJ and dissipate the same.
- Figure shows three different types of catcher – water basin type, submerged steel balls and TiB_2 plate type.



(a) Water basin (b) Steel/WC/ceramic balls (c) Catcher plates (TiB_2)

Fig. 1.12

1.11.1 Types of AWM

AWJ are mainly of two types,

i) Entrained type ii) Suspended type

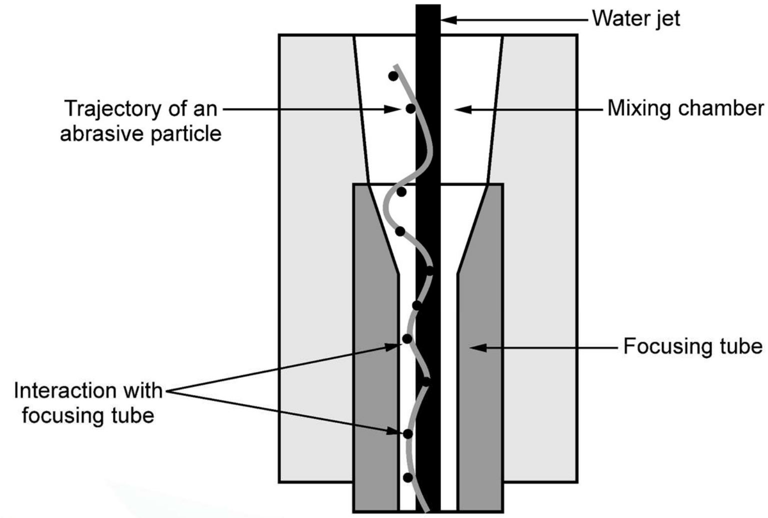


Fig. 1.13

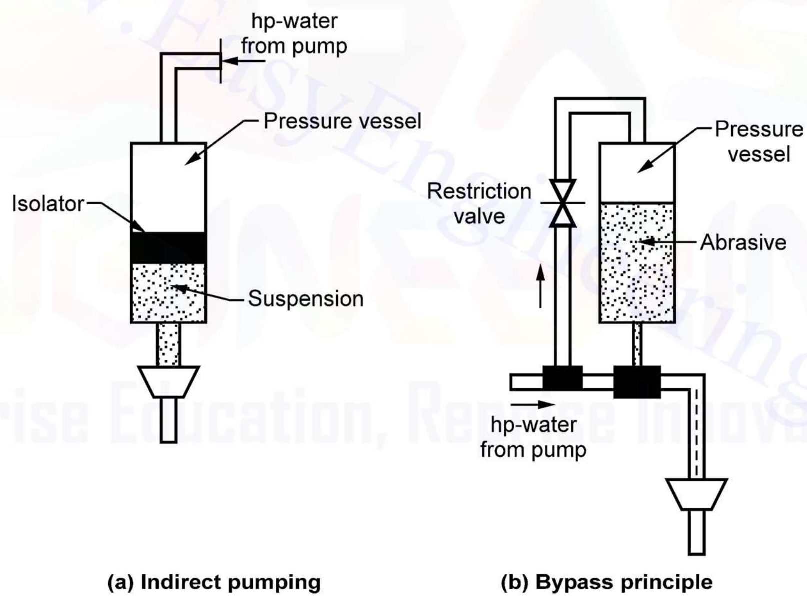


Fig. 1.14

- 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.
- In suspension AWJM the abrasive water jet is formed quite differently. There are three different types of suspension AWJ formed by direct, indirect and Bypass pumping method.

1.11.2 Process Variables

The process variables in AWJM are as follows :

- Flow rate and pressure of water
- Type, size and flow rate of abrasives
- Water nozzle and abrasive jet nozzle design
- Feed rate and stand - off distance
- Material of workpiece
- Number of passes
- Mixing tube dimensions (length, diameter and cutting angle)

1) Pressure of the water

- Pc is the minimum critical pressure required to cut the material.
- A minimum critical pressure Pc exits because of the minimum abrasive particle velocity
- required to cut specific materials.
- The value of Pc for mild steel is between 20.7 and 27.5 MPa.

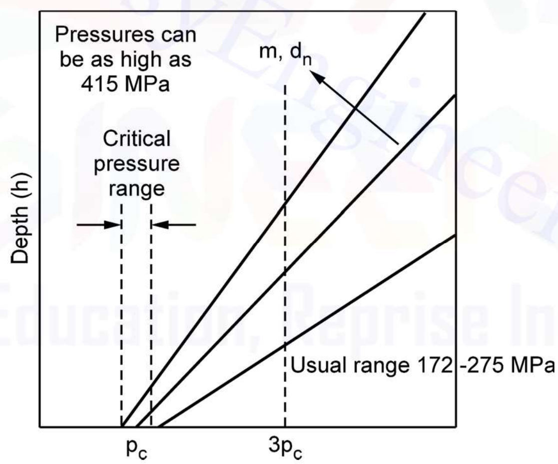


Fig. 1.15

2) Water flow rate

- Fig. 1.15 shows the depth of cut is affected by varying the water flow rate (increasing the nozzle diameter) while maintaining the constant pressure.
- As the flow rate increases, the slope of the curve decreases because the saturation point is reached.
- As the nozzle diameter increases and the water flow rate increases, the rate of increase in the particle velocity is reduced, thus reducing the depth of cut.

3) Abrasive flow rate

- Abrasive flow rate versus depth of cut is a linear relationship up to a point
- Above a critical flow rate, the cutting efficiency decreases.
- This is because of the fact that, as the abrasive flow rate increases (with a fixed water flow rate), particle velocity begins to decrease faster than the rate at which the number of abrasive particle impacts increase.

4) Abrasive particle size

- The most common abrasive particle sizes used for AWJM range from 100 to 150 grit
- An optimum abrasive particle size also exists for each particular nozzle mixing chamber configuration.

5) Abrasive type

- The type of abrasive used is also an important parameter.
- Garnet, silica and silicon carbide are the most commonly used abrasives.
- Selection of abrasive type is usually determined by the hardness of the material that is being cut.

6) Traverse rate

- When traverse rates are increased the depth of cut decreases.
- There is also a minimum critical traverse rate below which further increases in depth of cut are not obtained.
- If the traverse rate is not maintained at a relatively uniform velocity, a rough edge will result because of the nature of the process.

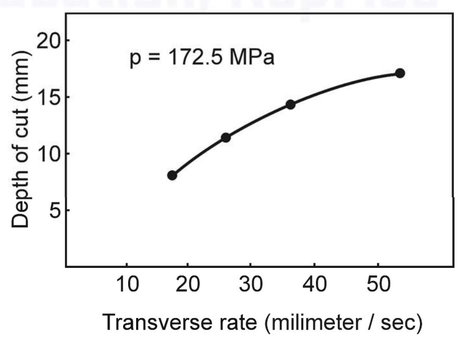


Fig. 1.16 Depth of cut Vs traverse rate

7) Stand-off-distance

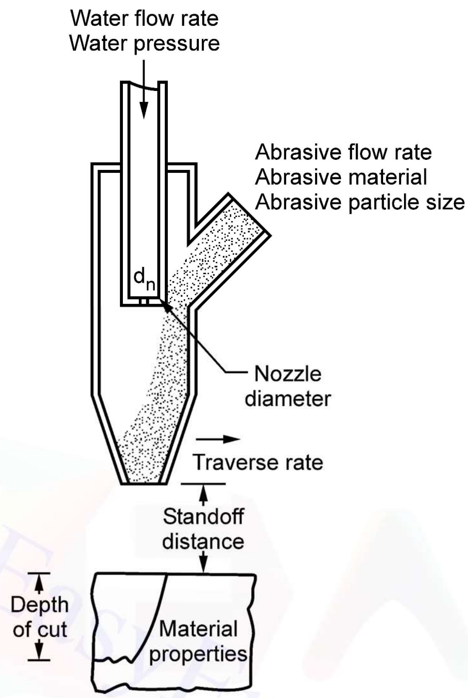


Fig. 1.17 Stand off distance

- Data generated by some researchers indicate that depth of cut is approximately linear relative to SOD. Increasing SOD decreasing the depth of cut.
- When mixing is efficient and process parameters are correct, a deviation in SOD of up to ±12.7 mm can be tolerated without degradation of the cut quality.
- If SODs are increased to a distances of about 80mm, the process will no longer cut but will efficiently clean and de-scale surfaces.

1.11.3 Process Capabilities

- AWJM can be thought of as a combination of WJM and AJM principles.
- But in terms of capability, AWJM combines the best of both processes, resulting in a new process that can cut materials whether they are hard or soft at high rates and in very thick sections.
- AWJM can cut materials as thick as 200mm and still maintain a comparatively narrow kerf.
- Kerf width is a function of the material thickness and usually is between 1.5 and 2.3 mm.
- The resulting taper on the cut edge is a function of the material hardness,

- Where hard materials have the widest kerf at the top of the cut and soft materials have the widest kerf at the bottom of the cut.

Advantages

- It can cut electrically non - conductive and hard materials rapidly and efficiently.
- Cutting speed is high.
- The process has multi-direction cutting capacity.
- No fire hazards and no dust problem.
- High quality of machined surface is obtained.
- Recycling of abrasive particles is possible.
- The process requires low power.
- During the process, no thermal or distortion stresses.
- Make all sorts of shapes with only one tool.
- No heat generated.
- Unlike machining or grinding, waterjet cutting does not produce any dust or particles that are harmful if inhaled.
- The kerf width in waterjet cutting is very small, and very little material is wasted.
- Waterjet cutting can be easily used to produce prototype parts very efficiently. An operator can program the dimensions of the part into the control station, and the waterjet will cut the part out exactly as programmed. This is much faster and cheaper than drawing detailed prints of a part and then having a machinist cut the part out.
- Waterjets are much lighter than equivalent laser cutters, and when mounted on an automated robot. This reduces the problems of accelerating and decelerating the robot head, as well as taking less energy.

Disadvantages

- This process can cut limited number of materials economically. During the cutting of tool steel and other hard materials, the cutting rate it low hence it require more time. This increases the cost of machining.
- Very thick parts with good dimensional accuracy cannot be cut by this process.
- Taper is also a problem with waterjet cutting in very thick materials. Taper is when the jet exits the part at a different angle than it enters the part, and can cause dimensional inaccuracy. Decreasing the speed of the head may reduce this, although it can still be a problem.

Applications

- This process is suitable for cutting of metals (copper, lead, tungsten, copper alloys, aluminium, tungsten carbide, etc.) and non - metals (graphite, silica, glass, concrete, acrylic, etc.).
- It is used to machine the sandwiched honeycomb structural material used in the aerospace industries.
- It is used for cutting materials in a number of industries like aerospace, oil, foundry, automotive, construction and glass.
- Different types of steels can be cut into different shapes like plate, tube, corrugated structure, etc.

1.12 Water Jet Machining (WJM)

Definition :

In this process high pressure and high velocity stream of water is used to cut the relatively softs and non-metallic materials like paper boards, wood, plastics, rubber, fibre glass, leather etc.,

Introduction

- Key element in WJM is a jet of water.
- Water jet travels at velocities as high as 900 m/s.
- When the water stream strikes a work piece surface, the erosive force of water removes the material rapidly.
- The water, in this case, acts like a saw and cuts a narrow groove in the work piece material.
- True cold cutting process – no HAZ (Heat Affected Zones), mechanical stresses or operator and environmental hazards

Principle

- The water jet machining involves directing a high pressure (150-1000 MPa) high velocity (540-1400 m/s) water jet (faster than the speed of sound) to the surface to be machined.
- The fluid flow rate is typically from 0.5 to 2.5 *l*tr/min
- The kinetic energy of water jet after striking the work surface is reduced to zero.
- The bulk of kinetic energy of jet is converted into pressure energy.

- If the local pressure caused by the water jet exceeds the strength of the surface being machined, the material from the surface gets eroded and a cavity is thus formed.
- Water is the most common fluid used, but additives such as alcohols, oil products and glycerol are added when they can be dissolved in water to improve the fluid characteristics.

Equipment

Typical work materials involve soft metals, paper, cloth, wood, leather, rubber, plastics, and frozen food. If the work material is brittle it will fracture, if it is ductile, it will cut well.

Water jet machining consists of :

1. Hydraulic pump	2. Intensifier	3. Accumulator
4. High pressure tubing	5. Jet Cutting nozzle	6. Catcher

1. Hydraulic pump

- Powered from a 30 kilowatt (kW) electric motor
- Supplies oil at pressures as high as 117 bars.
- Compressed oil drives a reciprocating plunger pump termed an *intensifier*.
- The hydraulic pump offers complete flexibility for water jet cutting and cleaning applications.
- It also supports single or multiple cutting stations for increased machining productivity.

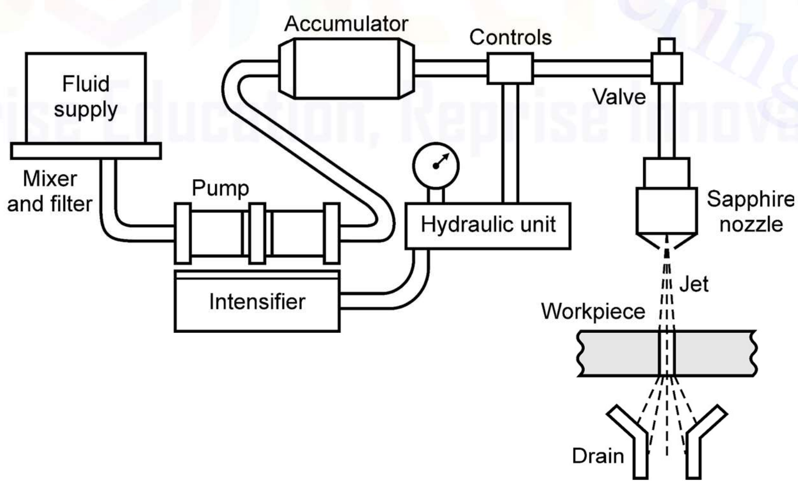


Fig. 1.18

2. Intensifier

- Accepts the water at low pressure (typically 4 bar) and expels it, through an accumulator, at higher pressures of 3800 bar.
- The intensifier converts the energy from the low-pressure hydraulic fluid into ultra high pressure water.
- The hydraulic system provides fluid power to a reciprocating piston in the intensifier center section.
- A limit switch, located at each end of the piston travel, signals the electronic controls to shift the directional control valve and reverses the piston direction.
- The intensifier assembly, with a plunger on each side of the piston, generates pressure in both directions.
- As one side of the intensifier is in the inlet stroke, the opposite side is generating ultra high pressure output.
- During the plunger inlet stroke, filtered water enters the high-pressure cylinder through the check value assembly.
- After the plunger reverses direction, the water is compressed and exits at ultrahigh pressure.

3. Accumulator

- Maintains the continuous flow of the high-pressure water and eliminates pressure fluctuations.
- It relies on the compressibility of water (12 percent at 3800 bar) in order to maintain a uniform discharge pressure and water jet velocity, when the intensifier piston changes its direction.

4. High pressure tubing

- Transports pressurized water to the cutting head.
- Typical tube diameters are 6 to 14 mm.
- The equipment allows for flexible movement of the cutting head.
- The cutting action is controlled either manually or through a remote-control valve specially designed for this purpose.

5. Jet cutting nozzle

- Nozzle provides a coherent water jet stream for optimum cutting of low-density, soft material that is considered unmachinable by conventional methods.
- Nozzles are normally made from synthetic sapphire.
- About 200 h of operation are expected from a nozzle, which becomes damaged by particles of dirt and the accumulation of mineral deposits on the orifice due to erosive water hardness.
- A longer nozzle life can be obtained through multistage filtration, which removes undesired solids of size greater than 0.45 μm.
- The compact design of the water jet cutting head promotes integration with motion control systems ranging from two-axis (*XY) tables to sophisticated multiaxis* robotic installations.

Recommended Nozzle Material	Operating Conditions
Carbide	Dirty, unfiltered water, Pressure below 140 MPa
Steel	Water filtered to 25 micron or better, pressure below 140 MPa
Sapphire	Water filtered to micron or better, Pressures above 140 MPa
Diamond nozzle shows better performance over sapphire nozzle at high pressure in terms of jet stability.	

6. Catcher

- Acts as a reservoir for collecting the machining debris entrained in the water jet.
- Moreover, it reduces the noise levels [105 decibels (dB)] associated with the reduction in the velocity of the water jet from Mach 3 to subsonic levels.

1.12.1 Process Parameters Affecting WJM

JET Nozzle

- Standoff distance - Gap between the jet nozzle (0.1 - 0.3 mm diameter) and the workpiece (2.5 - 6 mm).
- However for materials used in printed circuit boards, it may be increased to 13 to 19 mm.
- But larger the standoff distance, smaller would be the depth of cut.

- When cutting fiber-reinforced plastics, reports showed that the increase in machining rate and use of the small nozzle diameter increased the width of the damaged layer.

JET Fluid

- Typical pressures used are 150 to 1000 MPa to provide 8 to 80 kW of power.
- For a given nozzle diameter, increase in pressure allows more power to be used in the machining process, which in turn increases the depth of the cut.
- Jet velocities range between 540 to 1400 m/s.
- The quality of cutting improves at higher pressures by widening the diameter of the jet and by lowering the traverse speed.
- Under such conditions, materials of greater thicknesses and densities can be cut.
- Moreover, the larger the pump pressure, the greater will be the depth of the cut.
- The fluid used must possess low viscosity to minimize the energy losses and be noncorrosive, nontoxic, common, and inexpensive.
- Water is commonly used for cutting alloy steels.

Workpiece

- Brittle materials will fracture, while ductile ones will cut well.
- Material thicknesses range from 0.8 to 25 mm or more.
- Table above shows the cutting rates for different material thicknesses.

Material	Thickness, mm	Feed rate, m/mim
Leather	2.2	20
Vinyl chloride	3.0	0.5
Polyester	2.0	150
Kevlar	3.0	3
Graphite	2.3	5
Gypsum board	10	6
Corrugated board	7	200
Pulp sheet	2	120
Plywood	6	1

Applications

- WJM is used on metals, paper, cloth, leather, rubber, plastics, food, and ceramics.
- It is a versatile and cost-effective cutting process that can be used as an alternative to traditional machining methods.
- It completely eliminates heat-affected zones, toxic fumes, recast layers, work hardening and thermal stresses.
- It is the most flexible and effective cleaning solution available for a variety of industrial needs.
- In general the cut surface has a sandblast appearance.
- Moreover, harder materials exhibit a better edge finish.
- Typical surface finishes ranges from 1.6 μm Root Mean Square (RMS) to very coarse depending on the application.
- Tolerances are in the range of ± 25 μm on thin material.
- Both the produced surface roughness and tolerance depend on the machining speed.

1. Cutting

- WJM is limited to fibreglass and corrugated wood.
- Fig. 1.19 shows typical example of water jet cutting of water jet cutting of marble and application in the food industry.

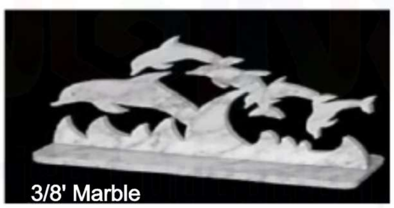


Fig. 1.19 Applications of WJM in marble cutting and food industries

2. Drilling

- The process drills precision-angled and -shaped holes in a variety of materials for which other processes such as EDM or EBM are too expensive or too slow.

3. Machining of fiber-reinforced plastics

- In this case the thermal material damage is negligible.
- The tool, being effectively pointed, accurately cuts any contours.
- The main drawback is the deflection of the water jet by the fiber embedded in the matrix, which protrudes after machining.

- The feed rate attainable depends on the surface quality required.
- Table below gives the limiting feed rates for water jet cutting of fiber-reinforced plastics.

Material	Thickness, mm	Feed rate, m/min
Glass fiber-reinforced polymers (GFRP) (laminate)	2.2	1.8 – 6.0
	3.0	1.4 – 5.0
	5.0	0.7 – 6.0
Aramid fiber-reinforced polymers (AFRP) (weave)	1.0	10.0
	2.0	2.4 – 4.0

4. Cutting of rocks

- Water jet cutting of a 51 mm deep slot in granite using two oscillating jets at 275 MPa during 14 passes at a 25.4 mm/s feed rate has been reported by McGeough (1988).
- Moreover an oscillating nozzle system operating at the same feed rate and pressure of 172 MPa, with the standoff distance adjusted every pass was used to cut a 178 mm deep slot in sandstone.

5. Deburring

- The method uses large pressures to remove large burrs (3 mm height) in 12 mm diameter drilled holes in a hollow molybdenum-chromium steel shaft at 15 s using 700 bar pressure and a flow rate of 27 L/min.
- In this method burrs are broken off by the impact of water.
- A higher pressure (4000 bar) and a lower flow rate (2.5 L/min) are used to remove burrs from nonmetallic materials.

6. Cutting of PCBs

- Using a small-diameter water jet, a printed circuit board (PCB) can be cut at a speed that exceeds 8 m/min, to the accuracy of ± 0.13 mm.
- Boards of various shapes for use in portable radios and cassette players can be cut using Computer Numerical Control (CNC) technology.

7. Surface treatment

- Removing deposits and residues without toxic chemicals, which eliminates costly clean up and disposal problems.

- Surface cleaning of pipes and castings, decorative finishing, nuclear decontamination, food utensil cleaning, degreasing, polishing, preparation for precise inspection, and surface texturing.
- Economical surface preparation and coating removal.
- Removing corrosion, spray residue, soluble salts, chemicals, and surface damage prior to recoating or painting.

8. Wire stripping

- Can remove the wire insulating material without damaging the metal or removing the tinning on the copper wire.
- Processing time can be decreased to about 20 % of the manual stripping method.

Advantages

- It has multidirectional cutting capacity.
- No heat is produced.
- Cuts can be started at any location without the need for predrilled holes.
- Wetting of the workpiece material is minimal.
- There is no deflection to the rest of the workpiece.
- The burr produced is minimal.
- The tool does not wear and, therefore, does not need sharpening.
- The process is environmentally safe.
- Hazardous airborne dust contamination and waste disposal problems that are common when using other cleaning methods are eliminated.
- There is multiple head processing.
- Simple fixturing eliminates costly and complicated tooling, which reduces turnaround time and lowers the cost.
- Grinding and polishing are eliminated, reducing secondary operation costs.
- The narrow kerf allows tight nesting when multiple parts are cut from a single blank.
- It is ideal for roughing out material for near net shape.
- It is ideal for laser reflective materials such as copper and aluminum.
- It allows for more accurate cutting of soft material.
- It cuts through very thick material such as 383 mm in titanium and 307 mm in Inconel.

Limitations

- Very thick parts can not be cut with water jet cutting and still hold dimensional accuracy. If the part is too thick, the jet may dissipate some, and cause it to cut on a diagonal, or to have a wider cut at the bottom of the part than the top. It can also cause a rough wave pattern on the cut surface.
- It is not suitable for mass production because of high maintenance requirements.

Water Jet Lag

Recent developments in WJM

- High pressure water jet
- Nozzle shape

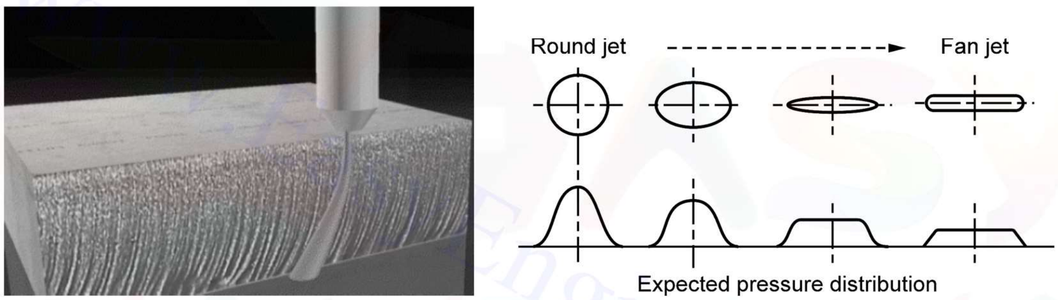


Fig. 1.20

- Water jet forming
- Water jet in mining
- Water jet in food processing plant
- Medical applications
- Water jet peening
- Water jet in packaging industry
- Water jet guided laser technology

1.13 Ultra-Sonic Machining

- The term ultrasonic is used to describe a vibratory wave of a frequency above that of the upper limit of the human ear.
- There are two types of waves namely shear wave and longitudinal wave.
- Longitudinal waves are mostly used in the ultrasonic applications, since they are easily generated.

Construction

- Fig. 1.21 shows the whole setup of Ultra Sonic Machining method. It consists of an electromechanical transducer for producing frequency upto 20 kHz to 30 kHz, which is more than the upper limit of audible frequency of the human ear, and makes the process silent.
- It also uses slurry of small abrasive particles which is forced against the workpiece by using a vibrating tool and it removes the material of workpiece in the form of small chips.
- The tool which is applied to the workpiece is generally made of soft materials and slurry is fed either manually or through pump. Sometimes hollow tools are also used because the slurry can feed through it easily.
- The transducer used in the process is made up of a magneto structive material, which is excited by the high frequency electric current and generates mechanical vibrations

Working

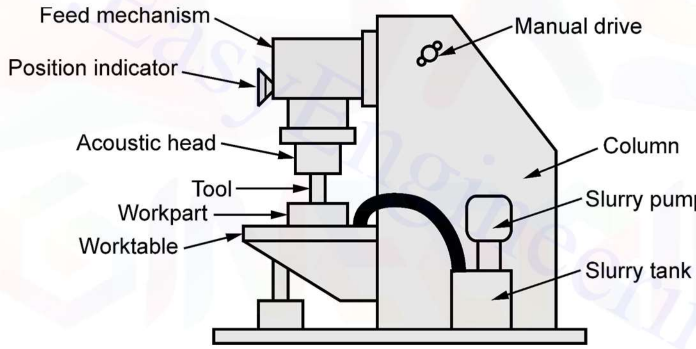


Fig. 1.21 Principal components of an ultrasonic machine

- A high frequency electric current is supplied by the ultrasonic oscillator to the ultrasonic transducer, which converts electrical energy into mechanical vibrations.
- To get the amplitude from 0.01 mm to 0.1 mm, vibrations of 20 kHz to 30 kHz are generated.
- These vibrations are transmitted to the cutting tool through the transducer cone, connecting body and tool holder.
- Due to these vibrations, tool vibrates in a longitudinal direction as shown in Fig. 1.21.
- The shape of the cutting tool is mirror image as that of which is produced on the workpiece.
- USM is also called as **Ultrasonic Grinding** or **Impact Grinding**.

Equipment :

Ultrasonic machining consists of :

1. Ultrasonic transducer
2. Concentrator
3. Tool
4. Abrasive slurry
5. Abrasive feed mechanism
6. Tool feed mechanism

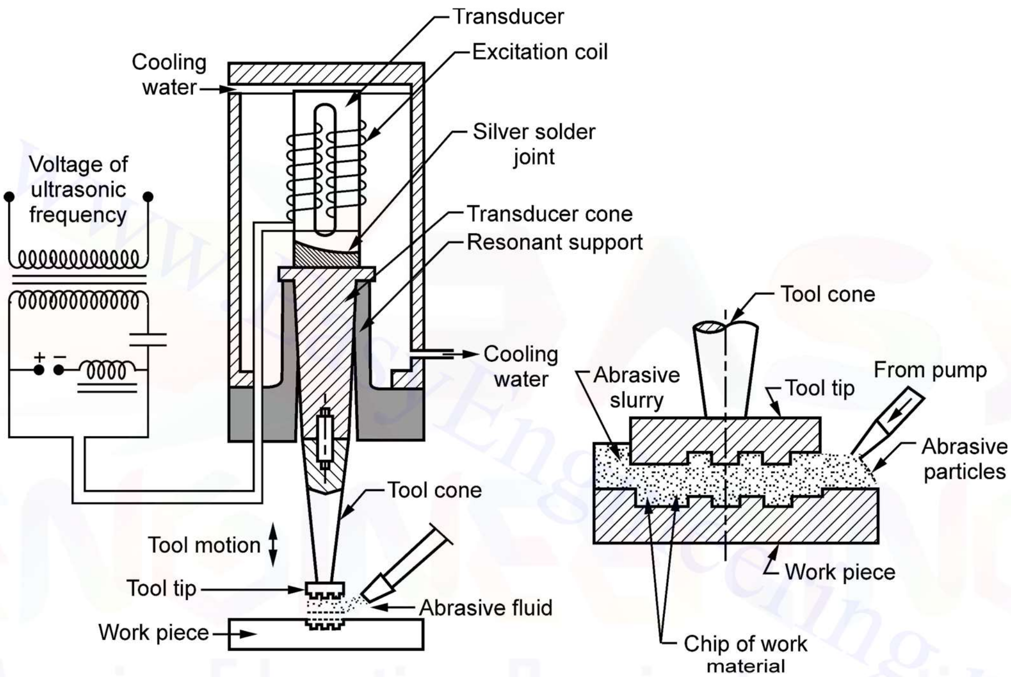


Fig. 1.22 Schematic representation of ultrasonic machining process

1. Ultrasonic transducer

The equipment consists an ultrasonic transducer for which the electrical input is given, to obtain the required mechanical vibration. The device used for converting any type of energy into ultrasonic waves or vibrations is called **ultrasonic transducer**. The electrical energy is converted into mechanical vibrations for carrying out the machining operation. The high frequency electrical signal is transmitted to traducer which converts it into high frequency low amplitude vibration. Essentially transducer converts electrical energy to mechanical vibration.

There are two types of transducer used

i) Piezo electric transducer

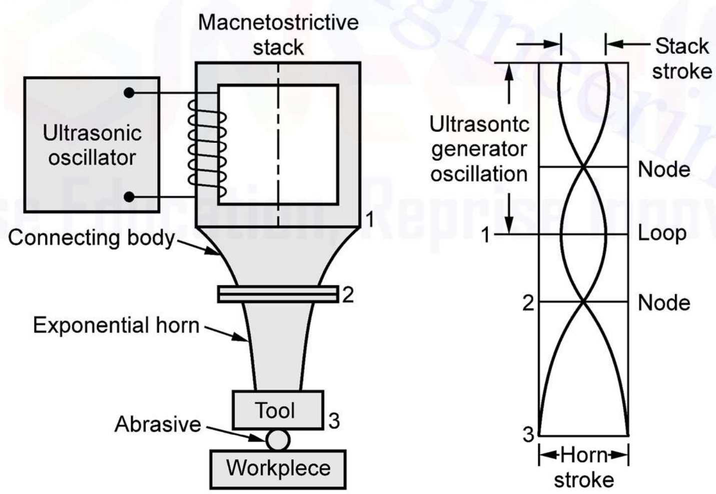
ii) Magneto-stricitve transducer.

i) Piezo electric transducer

- Piezo electric transducer have the capability of converting electrical energy into mechanical vibrations.
- These transducer generate a small electric current when they are compressed. Also when the electric current is passed though crystal it expands.
- When the current is removed, crystal attains its original size and shape. Such transducers are available up to 900 Watts. Piezo electric crystals have high conversion efficiency of 95 %.
  - More efficient
  - Less loss of power
  - Do not require cooling

ii) Magneto-strictive transducer :

- These also changes its length when subjected to strong magnetic field. (Magnetostrictive effect is the one in which the material changes its dimensions in response to a magnetic field).
- These transducer are made of nickel, nickel alloy sheets. Their conversion efficiency is about 20-30 %. Such transducers are available up to 2000 Watts.
- The maximum change in length can be achieved is about 25 microns.



(a) Scheme (b) Stroke magnification

Fig. 1.23

- The magnetostrictive transducer consists of an excitation coil wound around a laminated nickel core.

- The magnetostrictive materials employed are nickel, Iron-cobalt called Permendur, Iron-Aluminium as Alfer.
- Nickel is widely used because of its high strength and good insulating property. The nickel core present in the transducer unit contracts and expands in response to the influence of a rapidly alternating current.
- Under the action of the electromagnetic field, set up by the input electrical power supply, the magnetostrictive stack is periodically magnetized and its length changes. The periodical shortening and lengthening of the stack in synchronous with the generator frequency and initiates the vibration.
- The amplitude of vibration is of the order between 0.1 mm to 0.06 mm. Eddy current losses of the transformer can be reduced by using Ferro-magnetic material in the form of insulated laminations assembled into a pack.
- A fair amount of the given input energy to the transducer appears as a heat so cooling is necessary. If the machine is up to 50 W capacity, air cooling is sufficient. But for higher capacity 50 W water cooling must.
- Magnetostrictive transducer,
  - Generally found in old machines
  - Less efficient due to high eddy current losses
  - Requires cooling.
- The transducer may be of Piezo-electric or Magnetostrictive type depending upon the choice of the choice of operation to be performed on a specific work piece materials.
- The amplitude of vibration obtained from the transducer is inadequate for doing any operation and hence the tool is connected to the transducer by means of a concentrator to produce the desired amplitude at the tool end.

Notes : The electrical input circuit of an ultrasonic transducer consists of an **ultrasonic oscillator and power amplifier** (Also called generator) which converts low frequency Electrical energy (50 Hz) to High Frequency electrical energy (25 kHz).

2. Concentrator or tool holder or horn

- Concentrator provides the link between the tool and transducer. It is also called as **tool cone, horn, and wave guide or tool holder**. The tool holder holds and connects the tool to the transducer. It virtually transmits the energy and in some cases, increases the amplitude of vibration.

- The different types of concentrators used are,
    1. Exponential type
    2. Conical type
    3. Stepped type

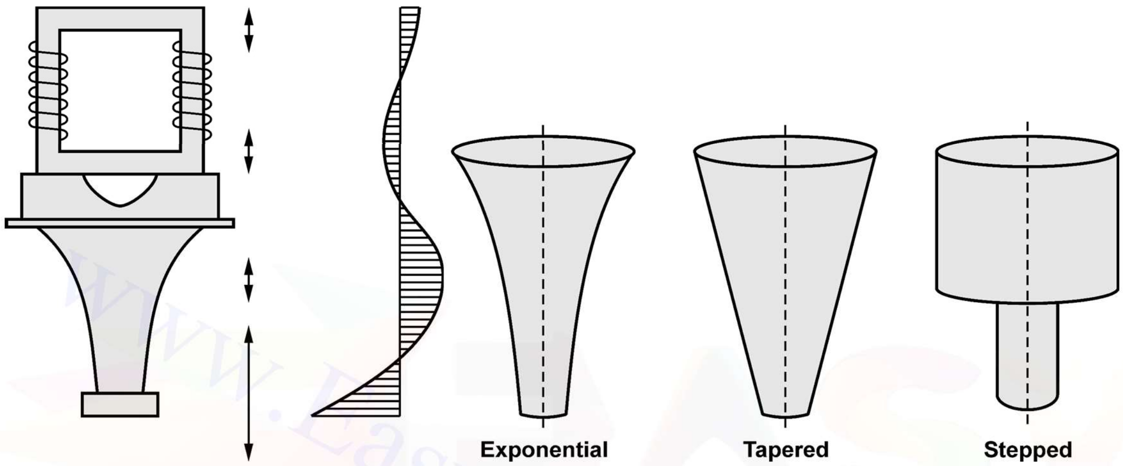


Fig. 1.24

Concentrator materials

- The horn or concentrator are generally made of monelmetal or stainless steel or titanium alloy or aluminium which can be fitted to the transducer either by brazing or to a connecting body made of Monel metal at a fixed nodal point.
- **Monel metal** (Monel is a group of **nickel alloys**, primarily composed of nickel (up to 67 %) and **copper**, with small amounts of iron, manganese, carbon, and silicon.) **is the best one** to be used as a tool holder which has properties of same as titanium and it can also be brazed easily.
- **Stainless steel is not preferred** because of its low fatigue strength. It is used only for low amplitude applications.

The tool holders or concentrators are available as

i) Non-amplifying type	ii) Amplifying type

i) Non-amplifying types produce the same amplitude of vibration at end where the tool is connected to the given input amplitude. They are normally of cylindrical cross section.

ii) Amplifying tool holders are capable of amplifying at end where the tool is connected and remove materials 10times faster than the non-amplifying type.

Disadvantages of amplifying concentrator :

- Higher fabrication cost.
- Poor surface finish.
- Need for frequent tuning to maintain resonance.
- Tool holders are more expensive, demand higher operating cost.

3. Tool

- Tool is normally fixed at the end of the concentrator.
- It is fixed either by brazing, soldering or fastened to the concentrator.
- It must be ductile and tough rather than hard.
- As the ratio of the work piece hardness and tool hardness increases the MRR decreases.
- In practice slenderness ratio of the tool should not exceed 20.
- A smaller contact area enhances better abrasive flow and so high penetration is obtained.
- Also if the cutting path is long, due to poor scavenging from the innermost areas, the cutting is inefficient.
- The tool shape is normally the mirror image of the cavity to be produced along with the tolerance for abrasive particle size and tool wear considerations.
- **Sonotrode :** In ultrasonic machining, welding and mixing, a **sonotrode** is a tool that creates ultrasonic vibrations and applies this vibrational energy to a gas, liquid, solid or tissue. Sonotrodes of small diameter are sometimes called probes.

> **Note :** The tool tip or tool face can be made from diamond, tool steel, Stainless steel, cold rolled steel, brass or copper.

4. Abrasive slurry

- The abrasive slurry is nothing but a mixture of abrasive grains and the carrier fluid generally water. The abrasive slurry is circulated by a pump between the tool and work piece interface.
- Some of the abrasive used are,

  1. Aluminium Oxide (Al_2O_3 Alumina)　　2. Boron carbide (B_4C)

  3. Silicon carbide (SiC)　　4. Diamond dust

  5. Boron silicarbide

Boron carbide	➢ Best and most efficient and fastest cutting abrasive. ➢ Expensive ➢ Used for cutting harder materials like tungsten carbide, tool steel and precious stones.
Silicon carbide	➢ Used for glass, germanium and some ceramics ➢ Used for maximum application
Alumina	➢ Less efficient than boron carbide
Aluminium oxide	➢ Loses its cutting ability due to poor wear resistance.

- Abrasives for USM are generally available in grit sizes ranging from 240 - 1000.

Grade	Grit size	Application
Coarse grits	200 - 400	Roughing work
Finer grits	800 - 1000	Finishing work
Extremely fine grits	1200 - 2000	Fine Finishing work (Where extreme accuracy is demanded)

- Selection of abrasives depends on hardness, usable life, cost and particle size.
- Fresh abrasives are preferred because of their good cutting ability and to sustain the removal rate.

Carrier Fluids

- The abrasive material is mixed with water (Carrier Fluid) to form an abrasive slurry.
- The most common abrasive concentration is water with 30 – 40 % by volume of the abrasives.
- The thinner mixtures are used to promote efficient flow when drilling holes or when forming complex cavities.
- The abrasive slurry should be replaced periodically.
- When water is used as a carrier fluid, some inhibitors are added to the water to improve its performance.

Notes : Other carrier fluids used are Benzene, Glycerol and some low viscosity oils.

Characteristics of carrier fluids

- Density approximately equal to that of the abrasives.
- Good wetting characteristics.
- High thermal conductivity and specific heat for efficient heat removal from the cutting area.
- Should have low viscosity.
- Should be non-toxic and easily available at cheap rate.
- Should be non-corrosive.

Functions of carrier fluid in USM

- Acts as an acoustic bond between the work piece and the tool.
- Acts as a coolant.
- Helps efficient transfer of energy.
- Acts as medium to carry the abrasive, machined materials and worn abrasives.

5. Abrasive feed mechanism

- Abrasive slurry is supplied through a nozzle by a pump. A good method is to keep the tool and the work piece in a bath of slurry.
- This ensures good supply of slurry and reduces any tendency of the tool to scatter the slurry when the amplitude is large.
- Another efficient method is to supply the slurry to the cutting zone through a hollow tool or through holes in the work piece.

6. Tool feed mechanism

- The objective of the tool feed mechanism is to apply the static load between the tool and the workpiece, during machining operation.
- It also brings the tool slowly, close to the workpiece surface and provides adequate, constant cutting force, then aids for the return of the tool as when desired. The sensitivity of feed is very important.
- Feed may either be given to the acoustic head or to the work piece, but in general feed motion is given to the acoustic head so as to facilitate positioning of the workpiece in X-Y direction.
- The tool feed mechanism controls the penetration rate and the depth of machining.

Functions of tool feed mechanism :

1. Bring the tool close to the workpiece, giving place for abrasive flow.
2. To provide the required impact force or cutting force and maintain throughout the operation as required.
3. Return the tool smoothly without damaging the cavity produced.

Types of feed mechanism

1. Spring type	2. Counter-weight type
3. Motor type	4. Pneumatic and hydraulic type

1. Spring type feed mechanism

- In this mechanism spring pressure is used to feed the tool during machining operation. This type of mechanism is preferred for its sensitivity and compactness.

2. Counter-weight type feed mechanism

- This mechanism is also called **Gravity feed** mechanism.
- In this mechanism, counter weight are used to apply the load to the head through a pulley as shown in Fig. 1.25(a) In order to reduce the friction, ball bearing are used.
- This mechanism is preferred for its simple construction. The force can be adjusted by varying the counter weights.
- This type is insensitive and inconvenient for adjustability during the operation.

3. Pneumatic and hydraulic type feed mechanism

- This is used for high rating machines. In order to get high feed rate, pneumatic feed mechanism is used.
- All the above types are provided with a tool displacement reading arrangement to know about the depth of penetration.

Working Principle

- When an AC power supply is given to the transducer, due to excitation, the transducer vibrates and the vibration is amplified by the horn or concentrator.
- The amplitude of vibration is maximum at the end of the tool holder where the tool is attached. The tool vibrates at the maximum frequency.

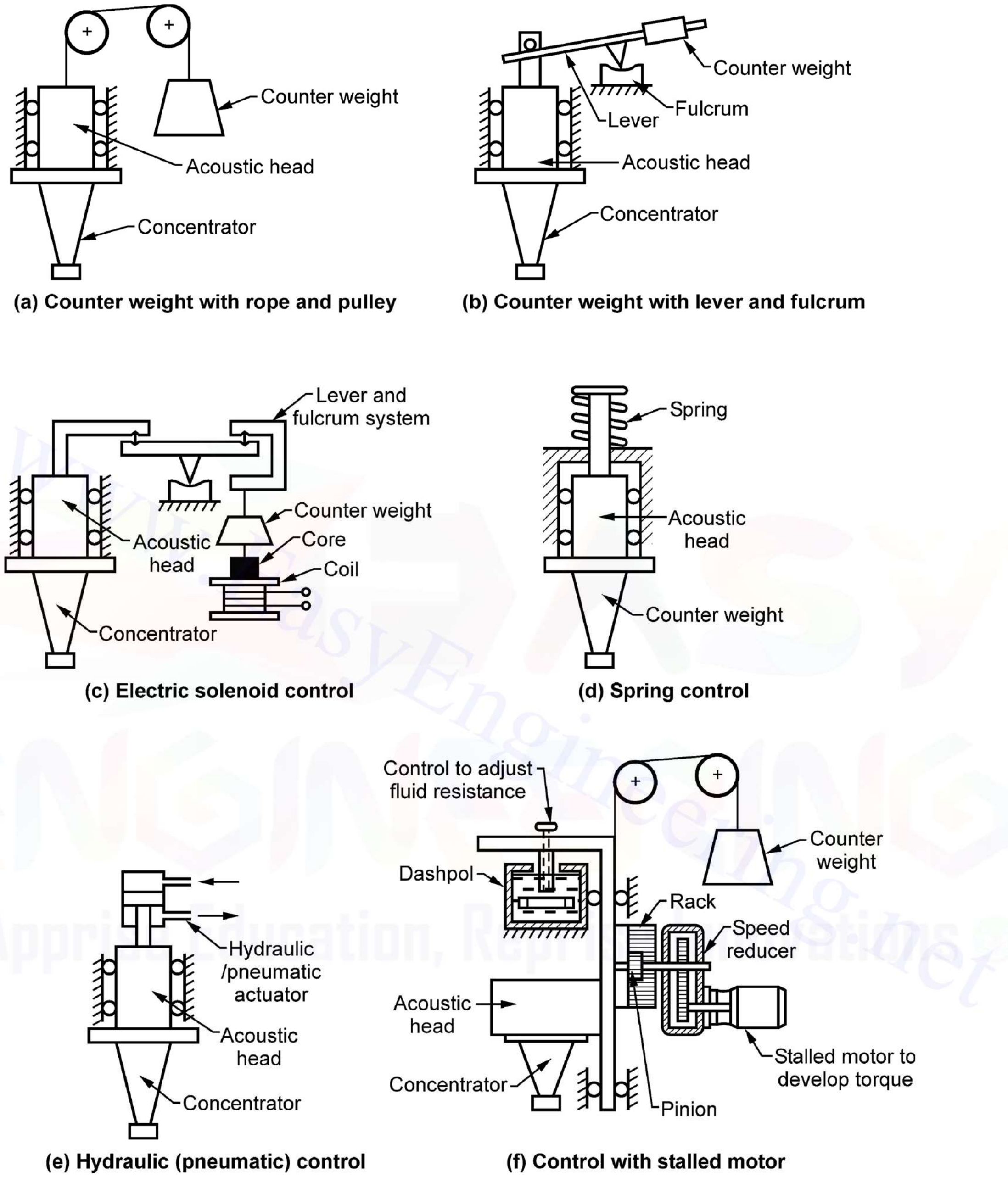


Fig. 1.25 Different types of feeding arrangements for USM

- The tool is fed on to the workpiece surface along with the supply of abrasive slurry. As the tool during vibration goes up and comes down, the abrasive particles entrapped between the tool and the workpiece surface are given impact on the workpiece surface.

- This impact causes the fracture and the particles are carried away by the circulating slurry of abrasive. Since the tool is the mirror image of the cavity to be produced, the tool feed mechanism aids for the formation of the cavity to the required shape.

Work Material

- Material removal method involved in this process is brittle fracture and obviously works only on relatively brittle materials.
- Any hard materials like stones, carbides, ceramics and brittle materials can also be machined.
- Any materials having high hardness >50 HRC like stainless steel, germanium, glass, ceramics etc., can be machined.

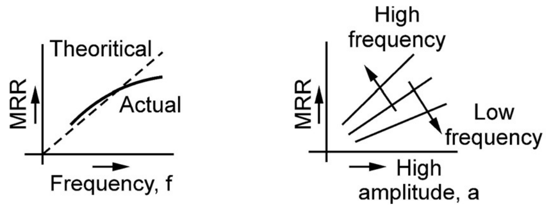
Mechanism and Material Removal

- In ultrasonic machining an abrasive slurry is pumped between tool and work, and the tool is given a high frequency, low amplitude oscillation, which in turn, transmits a high velocity to fine abrasive particles which are driven against the workpiece.
- At each stroke, minute chips of material are removed by fracture or erosion. Material Removal Mechanism involves both fracture and plastic deformation by impact of grains due to vibrating tool.

1.13.1 Process Variables of USM

1. Effect of amplitude and frequency of vibration on MRR

- Different researchers have different predictions on the effect of amplitude on MRR.
  - Rozenberg found that for a given material, the MRR is proportional to the square of the amplitude.
  - Miller has shown that the cutting rate bears a liner relationship with amplitude. According to him the MRR increase in amplitude and frequency.
  - Shaw showed that MRR is proportional to amplitude 3/4. He also predicted that the MRR is directly proportional to the first power of frequency for a fixed amplitude.
- Increases in frequency increases the number of blows on the grain particles impinging on the workpiece surface. So the MRR increases almost linearly with frequency.



Frequency ↑ MRR ↑

Fig. 1.26

2. Effect of particle velocity

- Markov has shown that the MRR is directly proportional to the particle velocity. So particle velocity increases the number of particles per impinging per unit time also increases.

Particle velocity ↑ MRR ↑

3. Effect of static loading or feed force

- The MRR increases with an increase in the feed force. But it tends to decrease beyond a critical value of the force, since the magnitude of the force crushes the abrasive grains thus decreasing its cutting ability and the MRR.
- As the feed force is more, the surface finish is good, because the grains are crushed to smaller size.

4. Effect of grain size

- As the grain size increases MRR also increases proportionally. However Grain size increases the MRR also increases till the grain size equals the amplitude of vibration. Beyond this, the MRR decreases due to effect of crushing of grains.

5. Effect of hardness ratio

- The ratio of workpiece hardness to tool hardness affects the MRR significantly in a way that as the ratio increases the MRR decreases according to the trend shown in graph.
- The Brittle materials are machined more rapidly than the ductile materials.

6. Effect of grain size (Grain diameter)

- Regarding the surface finish, when the grain size increases the surface roughness also increases and vice versa.
- Grain size also affects the accuracy of the cavity to be produced. Normally the hole is cut larger than the size of the tool owing to the flow of abrasive slurry along the sides and bottom of the tool.

7. Effect of viscosity

- The MRR drops appreciably when the viscosity increases, because the increase in viscosity tends to dampen the oscillations of the grains, thus decreasing the energy provided on the workpiece.

8. Effect of abrasive slurry concentration

- The abrasive slurry should flow easily under the gap between the tool and the workpiece surface.
- The slurry concentration directly controls the number of grains producing impact and the magnitude of the impact.
- The concentration increases the MRR also increases. The trend of increase in the number of grain for the unit volume of liquid media disturbing the power of impact to all the grains.

1.13.2 Process Capability

1. Can machine work piece harder than 40 HRC to 60 HRC like carbides, ceramics, tungsten glass that cannot be machined by conventional methods
2. Tolerance range 7 micron to 25 microns
3. Holes up to 76 micron have been drilled hole depth upto 51mm have been achieved easily. Hole depth of 152 mm deep is achieved by special flushing techniques.
4. Aspect ratio 40:1 has been achieved
5. Linear material removal rate – 0.025 to 25 mm/min
6. Surface finish – 0.25 micron to 0.75 micron
7. Non directional surface texture is possible compared to conventional grinding
8. Radial over cut may be as low as 1.5 to 4 times the mean abrasive grain size.

Material removal models in USM

Theoretical analysis and experimental results have revealed that USM is a form of abrasion and material removal in the form of small grains by four mechanisms

1. Throwing of abrasive grains
2. Hammering of abrasive grains
3. Cavitation’s in the fluid medium arising out of ultrasonic vibration of tool.
4. Chemical erosion due to micro – agitation

Material removal due to throwing and hammering is significant and MR due to cavitation and chemical erosion can be ignored. Abrasive particles are assumed to be spherical in shape having diameter (dg). Abrasive particles move under high frequency vibrating tool.

There are two possibilities when the tool hit the particle.

- If the size of the particle is small and gap between the tool and work is large, then particle will be thrown by tool to hit the work piece.
- If the size of the particle is large and gap between tool and work is small, then particle is hammered over the work surface.

Advantages

1. It can be used machine hard, brittle, fragile and non-conductive material.
2. No heat is generated in work, therefore no significant changes in physical structure of work material.
3. Non-metal (because of the poor electrical conductivity) that cannot be machined by EDM and ECM can very well be machined by USM.
4. It is burr less and distortion less processes.
5. Capability of drilling circular, no-circular holes in very hard materials like stones, carbides, ceramics and exceptionally brittle materials.
6. Bur less process.
7. No thermal effects on the machined workpiece.
8. Low cost of metal removal.
9. It can be adopted in conjunction with other new technologies like EDM, ECG, and ECM.
10. Equipment is safe to operate.

Disadvantages

1. Low metal removal rate. Not suitable for heavy stock removal.
2. It is difficult to drill deep holes, as slurry movement is restricted.
3. Tool wear rate is high due to abrasive particles. Tools made from brass, tungsten carbide, MS or tool steel will wear from the action of abrasive grit with a ratio that ranges from 1:1 to 200:1
4. USM can be used only when the hardness of work is more than 45 HRC.
5. Frequent tuning is required.
6. Not economical for soft materials.

Limitations

1. Low MRR
2. Depth of cylindrical holes produced is limited by the abrasive transport system.
3. High tooling cost.
4. Periodic replacement of abrasive slurry.
5. Tendency of tools to 'break out' at the bottom owing to static load and amplitude.
6. Inability to machine soft material.

Applications

1. Machining of cavities in electrically non-conductive ceramics
2. Diamond, tungsten, tungsten carbide, gem stones and synthetic ruby can be successfully machined.
3. Used to machine fragile components.
4. Used for multistep processing for fabricating silicon nitride (Si_3N_4) turbine blades
5. Large number of holes of small diameter. 930 holes with 0.32 mm has been reported (Benedict, 1973) using hypodermic needles
6. Used for machining hard, brittle metallic alloys, semiconductors, glass, ceramics, carbides etc.
7. Used for machining round, square, irregular shaped holes and surface impressions.
8. Used in machining of dies for wire drawing, punching and blanking operation
9. USM can perform machining operations like drilling, grinding and milling operations on all materials which can be treated suitably with abrasives.
10. USM has been used for piercing of dies and for parting off and blanking operations.
11. USM enables a dentist to drill a hole of any shape on teeth without any pain
12. Ferrites and steel parts, precision mineral stones can be machined using USM
13. USM can be used to cut industrial diamonds
14. USM is used for grinding Quartz, Glass, ceramics, Cutting holes with curved or spiral centre lines and cutting threads in glass and mineral or metallic-ceramics
15. Gang drilling can be done by employing USM process.

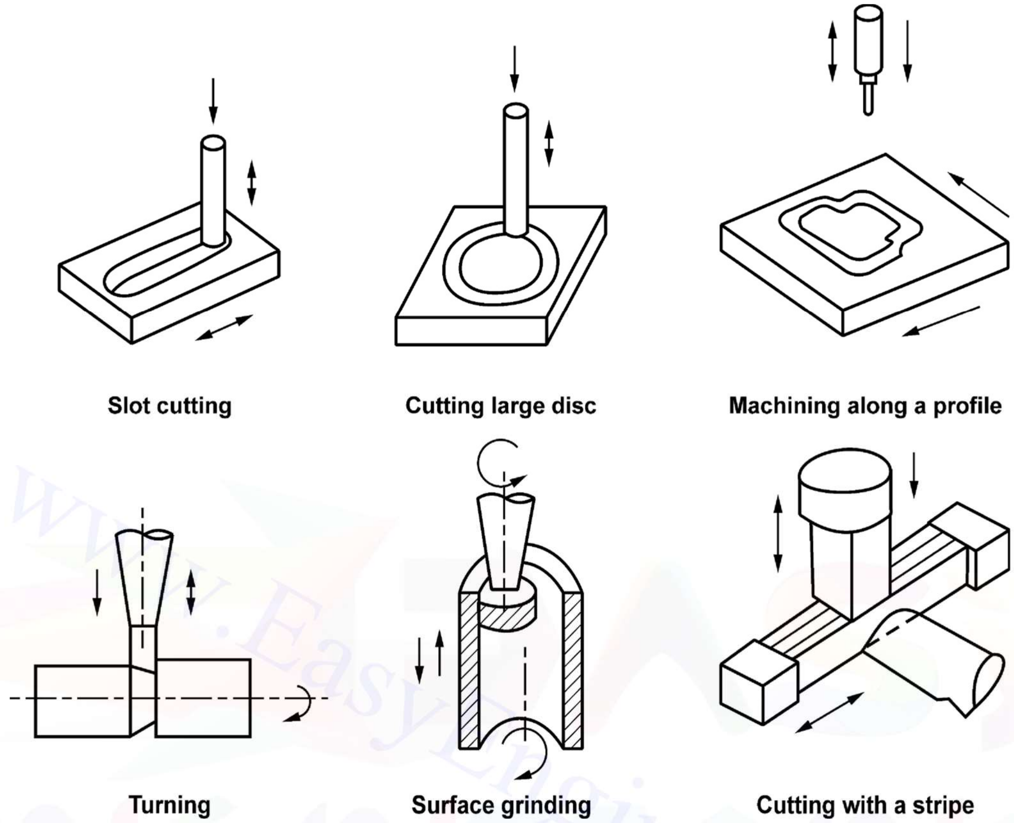


Fig. 1.27 Some applications of USM

1.14 Two Marks Questions with Answers

Part - A

Q.1 *What are the characteristics of unconventional machining process ?* ***(Section 1.1.1)***

Q.2 *List the unconventional machining process, which uses mechanical energy.*

Ans. :

- Abrasive Jet Machining
- Abrasive Water Jet Machining
- Water Jet Machining
- Ultrasonic Machining.

Q.3 *What is the necessity for UCMP ?* **(Section 1.1.2)**

Q.4 *How non-traditional machining processes are classified.* **(Section 1.3)**

Q.5 *What are the importances of UCMP ?* **(Section 1.1.2)**

Q.6 *Explain the classification of UCMP according to major energy source employed.* **(Section 1.3)**

Q.7 *Distinguish traditional and non-traditional machining process.* **(Section 1.2)**

Q.8 *What types of energy are employed in non-traditional machining process ?* **(Section 1.4)**

Q.9 *Enlist the requirement that demands the use of advanced machining process.* **(Section 1.1.2)**

Q.10 *Why unconventional machining process is not so effective on soft materials like Aluminium?*

Ans. : Unconventional machining process is not so effective on soft metals like aluminium, because accuracy cannot be maintained due to more metal removal rate.

Q.11 *How will you compare various non-traditional processes ?* **(Section 1.3.1)**

Q.12 *What are the different machining characteristics with respect to which the non traditional machining process can be analysed ?*

Ans. : Material removal rate, accuracy, surface finish, cutting speed, feed, depth of cut

Q.13 *What are the industrial needs for unconventional machining processes ?*

Ans. : To machine high steel alloys.

To generate desired complex surfaces and.

To achieve high accuracy and surface finish.

Q.14 *Write down the energy transfer media, energy source and mechanism of metal removal for the following process.*

Ans. : a) Water Jet Machining b) Electrochemical Grinding.

Processes	Energy transfer media	Energy source	Mechanism of metal removal
Water Jet Machining	High velocity water jet	Hydraulic pressure	Erosion
Electrochemical Grinding.	Electrolyte	Electrical source and mechanical movement	Ion displacement

Q.15 *Name the important factors that should be considered during the selection of an unconventional machining process for a given job.*

Ans. :

i) Physical parameters

ii) Shapes to be machined

iii) Process capability or machining characteristics

iv) Economic considerations.

Q.16 *Classify modern machining process on the basis of the type of energy employed.*
mechanical, thermal, chemical and electrochemical.

Q.17 *Mention thermal energy based unconventional machining process.*
laser beam machining, plasma arc machining, electron beam machining.

Q.18 *What are the advantages of unconventional machining processes ?*

Ans. :
- High accuracy and surface finish.
- No direct contact of tool and workpiece, so there is less/no wear.
- Quieter operation.

Q.19 *List the unconventional machining process based on chemical energy*

Ans. : Chemical Machining, Electro Chemical machining, Electro Chemical Grinding

Q.20 *Suggest a suitable unconventional machining process to cut a thin glass plate into two pieces.*

Ans. : Process like ECM, EDM, PAM, EBM are ruled out because they are suitable to machine only electrically materials

WJM, AWJM, USM can be used for machining.

Based on accuracy required any one process can be selected.

Q.21 *What is the transfer medium in AJM ?*

Ans. : High velocity particles.

Q.22 *Write the applications of AJM.* **(Section 1.10.2)**

Q.23 *List any four variables in AJM that influence the MRR.*

Ans. : Carrier Gas, Jet Velocity, Stand of distance, mixing ratio.

Q.24 *What are the various abrasives used in AJM process ?*

Ans. : Uniform particles of sand, steel grit, copper slag, walnut shells, and powdered **abrasives** are **used**.

Q.25 *Why abrasive jet machining process is not recommended to machine ductile materials.*

Ans. : While machining ductile materials by AJM, the hard abrasive grits may get embedded on the soft machined surface. This obstructs cut quality as well as properties and appearance of machined surface.

Q.26 *Write the formula for MRR for ductile and brittle materials in AJM.*

Ans. :

$$\therefore \quad MRR_{brittle} = 1.04 \frac{M_g \cdot U^{3/2}}{\rho_g^{1/4} \cdot H^{3/4}}$$

$$\therefore \quad MRR_{ductile} = 0.5 \frac{M_g U^2}{H}$$

U = Velocity of abrasive jet at the point of impact.

H = Flow strength or hardness of the work material.

M_g = Mass flow rate of abrasive particles.

ρ_g = Density of each abrasive particle.

Q.27 *Reuse of abrasives is not recommended in AJM process. Why ?*

Ans. : Reuse of abrasives is not recommended since the cutting ability of **abrasive** decrease after the usage and also the contamination of wear materials clogging the nozzle and the cutting unit orifice.

Q.28 *What is the principle of WJM ?* **(Section 1.12 (Principle))**

Q.29 *List the applications of WJM.* **(Section 1.12.1 (Applications))**

Q.30 *List the process parameters of WJM.*

Ans. : Jet Nozzle, jet Fluid, Workpiece

Q.31 *Mention the application of catcher in water jet machining.*

Ans. : Acts as a reservoir for collecting the machining debris entrained in the water jet. Moreover, it reduces the noise levels associated with the reduction in the velocity of the water jet.

Q.32 *List out the limitations of WJM process.*

Ans. : Very thick parts cannot be machined.

It is not suitable for mass production because of high maintenance requirements.

Q.33 *Write the typical applications of ultrasonic machining.*

Ans. :

- **Machining** very precise and intricate shaped articles.
- Drilling the round holes of any shape.
- Grinding the brittle materials.
- Profiling the holes.
- Engraving.
- Trepaning and coining.

Q.34 *What is the effect of abrasive grain size on machining rate in USM ?* **(Section 1.13.1 (Point no. 6))**

Q.35 *What is the need for transducer in USM ?*

Ans. : The transducer, which generates the ultrasonic vibration based on piezoelectric effect. It converts electrical energy to mechanical vibrations.

Q.36 *State the working principle of USM.* **(Section 1.13 (Working))**

Q.37 *List the applications of USM ?* **(Section 1.13.1(Applications))**

Q.38 *List the process parameters of USM.*

Ans. : Effect of particle velocity

Effect of grain size

Effect of hardness ratio

Effect of viscosity.

Q.39 *List out the abrasive materials used in ultrasonic machining process.*

Ans. : Silicon Carbide, Aluminium Oxide, Boron Carbide

Q.40 *What are the advantages of ultrasonic machining?* **(Section 1.13.2 (Advantages))**

1.15 Long Answered Questions

Part - B

Q.1 *Compare the mechanical and electrical energy processes in terms of physical parameters, shape capabilities, process capability and process economy.* **(Section 1.3.1)**

Q.2 *Explain the reasons for the development of UCMP. Discuss about the criteria recommended in selection of these processes.* **(Sections 1.1.2 and 1.4.4)**

Q.3 *i) Explain the factors that should be considered during the selection of an appropriate unconventional machining process for a given job.* **(Section 1.8)**

ii) Compare and contrast the various unconventional machining process on the basis of the type of energy employed, material removal rate, transfer media and economical aspects. **(Section 1.4.4)**

Q.4 *Make a comparison between traditional and unconventional machining processes in terms of cost, application, scope, machining time, advantages and limitations.* **(Section 1.2)**

Q.5 *For different non-conventional processes, present in the form of table, various process parameters recommended.* **(Section 1.8)**

Q.6 *How will you analyse the applicability of different processes to different types of materials, namely metals, alloys and non-metals ? Presentation in the form of table is preferred.* **(Section 1.5.3)**

Q.7 *What are the basic limitations of conventional manufacturing process ? Justify the need of unconventional machining process in today's industries.*

(Sections 1.1 & 1.1.1)

Q.8 *Explain the principle of working of the AJM process with its advantages, disadvantages, limitations and applications.* **(Sections 1.10 and 1.10)**

Q.9 *With a neat sketch explain the operation and effect of process parameters of AJM. List the applications.* **(Sec 1.10.2 (Process Parameter))**

Q.10 *Explain the principle of AJM. Mention some of the specific applications. Discuss in detail about the AJM process variables that influence the rate of material removal and accuracy in the machining.* **(Sections 1.10 and 1.10.2)**

Q.11 *Write the names of various elements of Abrasive Jet Machining (AJM) and explain them in brief.* **(Sec 1.10 (Equipment))**

Q.12 *Compare the types of nozzle design employed in AWJM with neat sketches.* **(Fig 1.11)**

Q.13 *Describe the process parameters of abrasive Jet machining along with the effect of all the process parameters.* **(Section 1.10.2)**

Q.14 *Explain the different applications and process control features of WJM. Describe the principle and equipment for WJM.* **(Section 1.12)**

Q.15 *Discuss the process parameters in WJM process.* **(Section 1.12.1)**

Q.16 *List the application and limitation of WJM.* **(Section 1.12.1 (Application and Limitations))**

Q.17 *Explain the principle of Ultrasonic Machining (USM) and its equipment. Explain the factors which influence the Metal Removal Rate (MRR) in USM.*

(Sections 1.13 and 1.13.1)

Q.18 *Explain the following in detail.*

a. Types of Transducers for USM **(Section 1.13 (Transducer))**

b. Feed Mechanisms in USM. **(Section 1.13 (Types of feed mechanism))**

c. Typical Applications of USM. **(Section 1.13.2 (Applications))**

d. Abrasives for USM. **(Section 1.13 (Abrasive Slurry))**

Q.19 *List the various types of tool holders and transducers used in ultrasonic machining and explain them briefly.*

(Section 1.13 (Transducer), Section 1.13 (Types of feed mechanism))

Q.20 *Discuss the effects of the following parameters on the MRR and surface finish in USM.* **(Section 1.13.1)**

a. Amplitude and frequency

b. Abrasive rates

c. Concentration of abrasives

d. Material hardness.

Q.21 *Explain the USM machine Set-up and discuss various feed mechanisms.*

(Section 1.13 (Types of feed mechanism))

Q.22 *Explain the principle of USM with neat diagram.* **(Section 1.13)**

Q.23 *List the commonly used abrasive powder for the tooling of USM and their properties.* **(Section 1.13 (Abrasive Slurry))**

Q.24 *Discuss in detail about the methods of generating the ultrasonic, characteristics of the various types of tool holder and tool feed mechanisms in USM.* **(Section 1.13)**

Q.25 *Compare USM. WJM and AJM in terms of process capabilities and limitations.* **(Section 1.5.2)**

Q.26 *How are ultrasonic vibrations generated in USM process?* **(Section 1.13)**

1.16 Multiple Choice Questions with Answers

INTRODUCTION

Q.1 Non-traditional machining is recommended when we need which of the following features ?

a Complex shapes
b High surface quality
c Low-rigidity structures
d All of the mentioned **[Ans. : d]**

Q.2 Non-traditional machining can also be called as ________.

a contact machining
b non-contact machining
c partial contact machining
d half contact machining **[Ans. : b]**

Q.3 In which of the following industries, Non-traditional machining methods play an important role ?

a Automobile
b Aerospace
c Medical
d All of the mentioned **[Ans. : d]**

Q.4 Different classifications of Non-traditional machining based on source of energy are ________.

a mechanical
b thermal
c chemical and electro-chemical.
d all of the mentioned **[Ans. : d]**

Q.5 In mechanical machining, material is removed by ___________

a erosion
b corrosion
c abrasion
d vaporization **[Ans. : a]**

Q.6 Material in thermal machining is removed by which of the following means ?

a Vaporization
b Melting
c Electro-plating
d All of the mentioned **[Ans. : d]**

Q.7 Which of the following process comes under mechanical machining ?

a USM
b EDM
c LBM
d PAM **[Ans. : a]**

Q.8 Surface defects that may be occurred during thermal machining are ________.

a micro cracking
b heat affected zones
c Striations
d all of the mentioned **[Ans. : d]**

Q.9 Sources used in thermal machining are ________.

a ions
b plasma
c electrons
d all of the mentioned **[Ans. : d]**

Q.10 Vacuum is the machining medium for ________.

a LBM b WJM

c EBM d none of the mentioned **[Ans. : a]**

Q.11 In chemical machining is material removal takes by ?

a Chemical reaction b Erosion

c Electron removal d None of the mentioned **[Ans. : a]**

Q.12 Which of the following is an example of hybrid machining ?

a Ultrasonic Machining b Electron Beam Machining

c Ultrasonic assisted electrochemical machining

d Laser Beam Machining **[Ans. : c]**

ABRASIVE JET MACHINING

Q.13 In advanced machining processes, what is the full form of AJM ?

a Automatic Jet Manufacturing b Abrasive Jet Machining

c Automated Jet Machining d Abrasive Jet Manufacturing **[Ans. : b]**

Q.14 In AJM, which of the following materials are used as abrasive grains ?

a Al_2O_3 b SiC

c Glass beads d All of the mentioned **[Ans. : d]**

Q.15 In abrasive jet machining, work piece material is removed by which of the following means ?

a Vaporization b Electro plating

c Mechanical abrasion d Corrosion **[Ans. : c]**

Q.16 Which type of materials can be machined using abrasive jet machining ?

a Glass b Ceramics

c Hard materials d All of the mentioned **[Ans. : d]**

Q.17 In machining system of AJM, which is the medium of carrying the abrasive grains for machining ?

a Liquids b Gases

c Any fluids d None of the mentioned **[Ans. : b]**

Q.18 In machining system of AJM, what is/are the gas/es used for carrying the abrasives?

a CO_2 b Air

c Nitrogen d All of the mentioned **[Ans. : d]**

Q.19 What is the pressure of gas that is to be supplied, for carrying the abrasives ?

a 0.1 to 1.0 kg/cm^2
b 2.0 to 8.0 kg $/cm^2$
c 10.0 to 18.0 kg/cm^2
d 25.0 to 35.5 kg/cm^2 **[Ans. : b]**

Q.20 Which of the following gas, should never be used as the carrier of abrasives ?

a Nitrogen
b CO_2
c Oxygen
d Air **[Ans. : c]**

Q.21 What is the frequency of mixing chamber, consisting of gas and abrasives ?

a 10 Hz
b 30 Hz
c 50 Hz
d 70 Hz **[Ans. : c]**

Q.22 In abrasive jet machining, what may be the size of the abrasive grains used ?

a 10 - 40 μm
b 50 - 100 μm
c 100 - 150 μm
d 200 - 300 μm **[Ans. : a]**

Q.23 What are the processes where abrasive jet machining can be used ?

a Cleaning
b Cutting
c Deburring
d All of the mentioned **[Ans. : d]**

Q.24 State whether the following statement is true or false.

"In Abrasive jet machining, commercial grades powders can be used for machining."

a True
b False **[Ans. : b]**

Q.25 In machining system of AJM, which of the following controls the relative motion between work piece and nozzle ?

a Cam drives
b Pantographs
c Trace mechanisms
d All of the mentioned **[Ans. : d]**

Q.26 Masks, which are used to confine the jet stream location on work piece are made of, which type of materials ?

a Copper
b Glass
c Rubber
d All of the mentioned **[Ans. : d]**

Q.27 In AJM, what is the mechanism of removal of material from the work piece ?

a Corrosion
b Abrasion
c Electron transfer
d Vaporization **[Ans. : b]**

Q.28 In AJM, abrasive jet from the nozzle follows, which type of path for a short distance ?

a Parallel
b Inclined
c Perpendicular
d None of the mentioned **[Ans. : a]**

Q.29 Which of the following components, influence the material removal rate in abrasive jet machining ?

a Nozzle
b Carrier gas
c Abrasive grains
d All of the mentioned **[Ans. : d]**

Q.30 In the following properties of nozzle, which of them does not influence the MRR ?

a Size
b Wear
c Outside temperature
d Distance from work piece **[Ans. : c]**

Q.31 In the following properties of abrasive grains, which of them changes rate of material removal ?

a Size
b Strength
c Shape
d All of the mentioned **[Ans. : d]**

Q.32 As the abrasive flow rate increases, what happens to the volumetric removal rate ?

a Increases
b Decreases
c Increase and then decrease
d Decrease and then increase **[Ans. : c]**

Q.33 What is the value of abrasive grain flow rate in abrasive jet machining ?

a 0.1 - 2 g/min
b 3 - 20 g/min
c 30 - 56 g/min
d 68 - 85 g/min **[Ans. : b]**

Q.34 What must be the velocity of the carrier gas that carries the abrasive particles ?

a 10 - 50 m/sec
b 50 - 150 m/sec
c 150 - 300 m/sec
d 300 - 500 m/sec **[Ans. : c]**

Q.35 What is the value of carrier gas flow rate in abrasive jet machining ?

a 6 L/min
b 17 L/min
c 28 L/min
d 39 L/min **[Ans. : c]**

Q.36 Which of the following material/s cannot be used for making of nozzle in abrasive jet machining ?

a Tungsten Carbide
b Steel Alloy
c Sapphire
d Synthetic Sapphire **[Ans. : b]**

Q.37 Which of the following values, does the diameter of the nozzle lies between ?

a 0.01 - 0.10 mm
b 0.30 - 0.50 mm
c 0.70 - 0.90 mm
d 1.10 - 1.50 mm **[Ans. : b]**

Q.38 What is the life of Tungsten Carbide material nozzle ?

a 1 - 8 hrs
b 2 - 5 hrs

c 10 - 15 hrs d 25 - 40 hrs **[Ans. : c]**

Q.39 In AJM, what is the life of synthetic sapphire material nozzle ?

a 100 hrs b 300 hrs

c 500 hrs d 700 hrs **[Ans. : b]**

Q.40 What are the tolerance limit values in abrasive water jet machining ?

a ± 0.01 mm b ± 0.03 mm

c ± 0.05 mm d ± 0.07 mm **[Ans. : c]**

Q.41 In AJM, surface roughness value will vary between which values ?

a 0.01 - 0.10 μm b 0.15 - 1.5 μm

c 2.0 - 5.0 μm d 7.0 - 10.0 μm **[Ans. : b]**

Q.42 Which of the following, are the processes and applications in which abrasive jet machining can be applied ?

a Drilling b Cutting

c Deburring d All of the mentioned **[Ans. : d]**

Q.43 Using abrasive jet machining, wire cleaning and insulation stripping take place without affecting the conductor.

a True b False **[Ans. : a]**

Q.44 In abrasive jet machining, intricate shapes and holes are machined on which type of materials ?

a Brittle b Thin

c Difficult to machine d All of the mentioned **[Ans. : d]**

Q.45 State whether the following statement is true or false, about abrasive jet machining.

"Using abrasive jet machining, micro deburring of hypodermic needles can take place."

a True b False **[Ans. : a]**

Q.46 What are the type of materials that can be machined using abrasive jet machining ?

a Glass b Sapphire

c Quartz d All of the mentioned **[Ans. : d]**

Q.47 What is the amount of material utilizes when we machine parts using Abrasive jet machining ?

a Very low b Low

c Medium d High **[Ans. : d]**

Q.48 After how much time tool has to be changed in AJM ?

a 1 hr
b 2 hrs
c 5 hrs
d No tool change required **[Ans. : d]**

Q.49 By using abrasive jet machining, how much amount of hardening does the materials experience ?

a No hardening
b Very less hardening
c Average hardening
d High hardening **[Ans. : a]**

Q.50 Which type of materials cannot be machined using abrasive jet machining ?

a Soft materials
b Hard materials
c Difficult to machine materials
d None of the mentioned **[Ans. : a]**

Q.51 Which of the following materials in abrasive jet machining can be a health hazard ?

a Abrasive grains
b Air carrier
c Silica dust
d None of the mentioned **[Ans. : c]**

Q.52 In AJM, air filters are used to remove which of the following ?

a Moisture
b Oil
c Other dust particles
d All of the mentioned **[Ans. : d]**

WATER JET MACHING

Q.53 What is the full form of WJM in advanced machining processes ?

a Water Jack Manufacturing
b Water Jet Machining
c Water Jet Manufacturing
d Water Jack Manufacturing **[Ans. : b]**

Q.54 What is the key element of water jet machining for material removal ?

a Tool Holder
b Work piece
c Water jet
d Power source **[Ans. : c]**

Q.55 What is the velocity of water jet stream in water jet machining ?

a 100 m/sec
b 300 m/sec
c 700 m/sec
d 900 m/sec **[Ans. : d]**

Q.56 Which of the following is not a part of machining system of water jet machining ?

a Transducer
b Accumulator
c Jet cutting nozzle
d Hydraulic pump **[Ans. : a]**

Q.57 What is the general power rating of the hydraulic pump, used in WJM ?

a 10 kW
b 20 kW
c 30 kW
d 40 kW **[Ans. : c]**

Q.58 Which of the following are the components of intensifier present in water jet machining system ?

a Piston
b Plunger
c Limit switch
d All of the mentioned **[Ans. : d]**

Q.59 Intensifier increases the pressure water by which of the following values ?

a 10 - 100 MPa
b 100 - 200 MPa
c 200 - 400 MPa
d 400 - 1000 MPa **[Ans. : c]**

Q.60 On which property of water, will the accumulator in water jet machining rely on ?

a Density
b Compressibility
c Viscosity
d Velocity **[Ans. : b]**

Q.61 What are the values of typical tube diameters in the machining system in WJM ?

a 0.1 to 1 mm
b 1 to 6 mm
c 6 to 14 mm
d 14 to 25 mm **[Ans. : c]**

Q.62 What is the expected life of the nozzles used in WJM ?

a 10 hrs
b 20 hrs
c 100 hrs
d 200 hrs **[Ans. : d]**

Q.63 Which of the following does not damage the nozzle used in Water jet machining ?

a Particles of dirt
b Mineral deposits
c Water
d All of the mentioned **[Ans. : c]**

Q.64 What are the uses of catcher in machining system of water jet machining ?

a Collecting dirt
b Collection of debris
c Reduce noise levels
d All of the mentioned **[Ans. : d]**

Q.65 Distance between which components, is the stand-off distance ?

a Nozzle-inlet and work piece top
b Nozzle-outlet and work piece-top
c Nozzle-inlet and work piece-bottom
d Nozzle-outlet and work piece-bottom **[Ans. : b]**

Q.66 What is the value of diameter of the jet cutting nozzle in WJM ?

a 0.01 - 0.1 mm
b 0.1 - 0.3 mm
c 0.3 - 0.7 mm
d 0.7 - 1.5 mm **[Ans. : b]**

Q.67 What is the value of stand-off distance in Water jet machining ?

a 0.1 - 1 mm b 1 - 2 mm

c 2 - 6 mm d 6 - 14 mm **[Ans. : c]**

Q.68 What are the values of jet velocities in water jet machining ?

a 100 - 200 m/s b 200 - 500 m/s

c 500 - 1500 m/s d 1500 - 3000 m/s **[Ans. : c]**

Q.69 State whether the following statement is true or false.

"As the pump pressure increases, depth of cut decreases in Water jet machining."

a True b False **[Ans. : b]**

Q.70 What is the value of material thickness of work piece in WJM ?

a 0.001 - 0.25 mm b 0.8 - 25 mm

c 50 - 100 mm d 100 - 500 mm **[Ans. : b]**

Q.71 What is the value of feed rate in Water Jet Machining ?

a 0.0001 - 0.025 m/min b 0.05 - 0.25 m/min

c 0.5 - 200 m/min d 200 - 500 m/min **[Ans. : c]**

Q.72 In WJM, what are the properties of jet fluid that affect the MRR ?

a Velocity b Flow rate

c Viscosity d All of the mentioned **[Ans. : d]**

Q.73 Which of the following property/ies of nozzle does not affect the material removal rate in Water jet machining ?

a Material b Diameter

c Outside temperature d Stand-off distance **[Ans. : c]**

Q.74 In the following materials, Water jet machining can be used on which type of material ?

a Metals b Plastics

c Ceramics d All of the mentioned **[Ans. : d]**

Q.75 What are the processes and applications, where water jet machining can be used?

a Cutting b Drilling

c Deburring d All of the mentioned **[Ans. : d]**

Q.76 What is the tolerance limit range of thin materials in WJM ?

a ± 0.1 mm b ± 10 mm

c ± 25 mm d ± 50 mm **[Ans. : c]**

Q.77 In cutting of rocks using water jet machining, which type of pressure is needed ?

a Low pressure
b Medium pressure
c High pressure
d None of the mentioned **[Ans. : c]**

Q.78 In deburring, which combination removes the material from non-metallic materials ?

a High pressure and low flow rate
b High pressure and high flow rate
c Low pressure and low flow rate
d Low pressure and high flow rate **[Ans. : a]**

Q.79 Which of the following materials has some drawbacks of cutting WJM ?

a Food
b Rocks
c Fibre-reinforced plastics
d None of the mentioned **[Ans. : c]**

Q.80 What is the accuracy level obtained when PCB's are cut by WJM ?

a ± 0.05 mm
b ± 0.13 mm
c ± 0.26 mm
d ± 0.33 mm **[Ans. : b]**

Q.81 In WJM, surface treatment includes which type of processes ?

a Removing deposits
b Removing chemicals
c Degreasing
d All of the mentioned **[Ans. : d]**

Q.82 In how many directions, can the cutting takes place in water jet machining ?

a Uni-directional
b Bi-directional
c Multi-directional
d None of the mentioned **[Ans. : c]**

Q.83 In Water jet machining, cuts can be started at which place of workpiece ?

a From left
b From right
c From middle
d From any point **[Ans. : d]**

Q.84 State whether the following statement is true or false.

"To start the cuts in Water jet machining, pre-drilled holes are not necessary."

a True
b False **[Ans. : b]**

Q.85 Which of the following is not an advantage of water jet machining ?

a Burr produced is minimal
b No Heat is produced
c Relatively low hourly rates
d Environmentally safe **[Ans. : c]**

Q.86 In Water jet machining, tool need not require sharpening once the machining is done.

a True
b False **[Ans. : a]**

Q.87 Which of the following secondary processes are eliminated in water jet machining ?

a Grinding of surface
b Surface treatment
c Polishing of surface
d All of the mentioned **[Ans. : d]**

Q.88 How many parts are cut using water jet machining, on a single blank ?

a One part
b Two parts
c Three parts
d Multiple parts

[Ans. : d]

Q.89 Which of the following is the disadvantage of water jet machining ?

a Narrow kerf width
b Small diameter of nozzle
c Not suitable for mass production
d Burr is minimal

[Ans. : c]

ABRASIVE WATER JET MACHINING

Q.90 In advanced machining processes, what is the full form of AWJM ?

a Automated Water Jet Machining
b Automated Water Jet Manufacturing
c Abrasive Water Jet Machining
d Abrasive Water Jet Manufacturing

[Ans. : c]

Q.91 What are all the types of materials, which can be machined using AWJM ?

a Glass
b Ceramics
c Concrete
d All of the mentioned

[Ans. : d]

Q.92 When was abrasive water jet machining developed first ?

a 1942
b 1958
c 1974
d 1980

[Ans. : c]

Q.93 When compared to the conventional machining, how much times faster, is the abrasive water jet machining ?

a 5 times
b 10 times
c 15 times
d 20 times

[Ans. : b]

Q.94 What is the percentage of the abrasives and water in the mixture ?

a 20 % water and 80 % abrasives
b 80 % water and 20 % abrasives
c 30 % water and 70 % abrasives
d 70 % water and 30 % abrasives

[Ans. : d]

Q.95 What are the materials used for abrasives in Abrasive water jet machining ?

a SiC
b Corundum
c Glass beads
d All of the mentioned

[Ans. : d]

Q.96 In the machining system of AWJM, which one accelerates the abrasives to remove material ?

a Water only
b Water jet stream
c Feeder
d None of the mentioned

[Ans. : b]

Q.97 The introduction of compressed air to the water jet enhances the deburring action.

a True
b False
[Ans. : a]

Q.98 What is the grain size of abrasive particles, which are often used for Abrasive water jet machining ?

a 0.01 - 0.50 μm
b 10 - 150 μm
c 200 - 500 μm
d 500 - 1000 μm
[Ans. : b]

Q.99 How is the material removed in abrasive water jet machining ?

a Vaporization
b Electron transfer
c Corrosion
d Erosion
[Ans. : d]

Q.100 Which of the following is not the feed mechanism of the abrasives in AWJM ?

a Side feed
b Cross feed
c Central feed
d All of the mentioned
[Ans. : b]

Q.101 In Abrasive water jet machining, how are the abrasives fed into the water jet stream ?

a Suspension
b Injection
c All of the mentioned
d None of the mentioned
[Ans. : c]

Q.102 What is the use of delivery system in the machining system of AWJM ?

a To deliver colloidal solution
b To pump water
c To fed abrasives
d None of the mentioned
[Ans. : b]

Q.103 Of the following components, which one does not come under the machining system of AWJM ?

a Water delivery system
b Transducer
c Cutting nozzles
d Mixing chambers
[Ans. : b]

Q.104 In abrasive water jet machining, intensifier is used to deliver which type of pressure ?

a Very low pressure
b Low pressure
c Medium pressure
d High pressure
[Ans. : d]

Q.105 In mixing chamber of AWJM, which of the following are mixed ?

a Abrasives and colloidal solution
b Abrasives and water jet
c Colloidal and water jet
d None of the mentioned
[Ans. : b]

Q.106 Of the following, which one is a type of suspension in AWJM ?

a Direct pumping
b Indirect pumping
c Bypass pumping
d All of the mentioned
[Ans. : d]

Q.107 In machining system of AWJM, mixing chamber is immediately followed by which of the following component ?

a Focusing tube
b Cutting nozzle
c Intensifier
d Water delivery
[Ans. : a]

Q.108 Which of the following energies are absorbed using the catchers in Abrasive water jet machining ?

a Pressure energy
b Kinetic energy of abrasives
c Residual energy
d All of the mentioned
[Ans. : c]

Q.109 Which of the following are different types of catchers used in AWJM ?

a Water basin type
b Submerged steel balls type
c TiB_2 type
d All of the mentioned
[Ans. : d]

Q.110 Which of the following is not a process parameter of abrasive water jet machining ?

a Frequency of vibration
b Orifice diameter
c Pressure
d Stand-off distance
[Ans. : a]

Q.111 Which of the following come under the process parameters of the abrasive water jet machining?

a Abrasive size
b Machine impact angle
c Traverse speed
d All of the mentioned
[Ans. : d]

Q.112 What is the value of orifice diameter in abrasive water jet machining ?

a 0.01 - 0.03 mm
b 0.03 - 0.09 mm
c 0.10 - 0.30 mm
d 0.30 - 0.90 mm
[Ans. : c]

Q.113 Of the following values, between which of them pressure value will range ?

a 1000 - 1500 bar
b 1500 - 2500 bar
c 2500 - 4000 bar
d 4000 - 10000 bar
[Ans. : c]

Q.114 When compared to sand, how much effective is garnet as abrasive material in AWJM ?

a 20 %
b 30 %
c 40 %
d 50 %
[Ans. : b]

Q.115 State whether the following statement is true or false about Abrasive water jet machining.

"A material, whose material removal rate is higher, produces larger surface roughness."

a True
b False
[Ans.: a]

Q.116 Surface roughness depends on which of the following parameters in abrasive water jet machining ?

a Work piece material — b Grit size

c Abrasive type — d All of the mentioned **[Ans. : d]**

Q.117 What is the value of focusing diameter in abrasive water jet machining ?

a 0.1 - 0.6 mm — b 0.8 - 1.4 mm

c 1.6 - 2.8 mm — d 3.2 - 5.2 mm **[Ans. : b]**

Q.118 Abrasive flow value in abrasive water jet machining will range between which of the following values ?

a 0.01 - 0.1 kg/min — b 0.1 - 1.0 kg/min

c 1.0 - 10 kg/min — d 10 - 100 kg/min **[Ans. : b]**

Q.119 What is the value of stand-off distance in abrasive water jet machining?

a 1.0 - 2.0 mm — b 2.0 - 4.0 mm

c 4.0 - 6.0 mm — d 6.0 - 10.0 mm **[Ans. : a]**

Q.120 Impact angle in Abrasive water jet machining range between which of the following values ?

a 0&#176 to 10&#176 — b 10&#176 to 30&#176

c 30&#176 to 90&#176 — d 90&#176 to 100&#176 **[Ans. : c]**

Q.121 Of the following values, between which values traverse speed will range ?

a 0.1 to 5 m/min — b 5 to 100 m/min

c 100 to 500 m/min — d 500 to 1000 m/min **[Ans. : b]**

Q.122 Depth of cut values in Abrasive water jet machining ranges between which values ?

a 0.01 to 2 mm — b 2 to 250 mm

c 300 to 500 mm — d 650 to 900 mm **[Ans. : b]**

Q.123 Who discovered USM ?

a Balamuth — b Paul O Flawer

c Turing — d Steve John **[Ans. : a]**

Q.124 What is the full form of USM in advanced machining process ?

a Ultrasound manufacturing — b Ultrasonic machining

c UV spectrum manufacturing — d Ultra sonar machining **[Ans. : b]**

Q.125 USM removes materials using the ____________ tool.

a Perpendicularly rotating
b Perpendicularly oscillating
c Axially oscillating
d Inclined oscillating

[Ans. : c]

Q.126 Which is softer material in USM ?

a Tool
b Work piece
c Tool and work piece
d None of the mentioned

[Ans. : a]

Q.127 Frequency of tool's oscillation in USM ranges between ________.

a 5-10 kHz
b 10-15 kHz
c 18-20 kHz
d 25-50 kHz

[Ans. : c]

Q.128 Amplitude of oscillation of tool in USM ranges between ________.

a 0.1-10 µm
b 10-40 µm
c 50-100 µm
d 100-1000 µm

[Ans. : b]

Q.129 In which year, discovery of USM took place ?

a 1910
b 1925
c 1943
d 1945

[Ans. : d]

Q.130 The machining system of USM contains which of the following components ?

a Magnetostrictor
b Concentrator
c Tools and slurry
d All of the mentioned

[Ans. : d]

Q.131 In ultrasonic machining, magnetostrictor is energized at ultrasonic frequency.

a True
b False

[Ans. : a]

Q.132 Of the following scientists, who discovered magnetostrictor effect ?

a Balamuth
b Steve O Flawer
c Joule
d Turing

[Ans. : c]

Q.133 In ultrasonic machining, magnetostrictor converts magnetic energy into which type of energy ?

a Mechanical energy
b Electrical energy
c Thermal energy
d None of the mentioned

[Ans. : a]

Q.134 What is the value of the amplitude obtained without mechanical amplifier ?

a 0.0001 - 0.001 µm
b 0.001 - 0.1 µm
c 1 - 10 µm
d 10 - 100 µm

[Ans. : b]

Q.135 What is the value of the amplitude obtained when we use mechanical amplifier ?

a 1 - 10 μm
b 10 - 40 μm
c 40 - 50 μm
d 50 - 100 μm
[Ans. : c]

Q.136 In USM, tool tips must have low resistance and fatigue strength.

a True
b False
[Ans. : b]

Q.137 At what rate slurry is pumped through nozzle in USM ?

a 10 L/min
b 25 L/min
c 50 L/min
d 75 L/min
[Ans. : b]

Q.138 By which of the following means, material is removed in USM ?

a Mechanical abrasion
b Microchipping
c Cavitation
d All of the mentioned
[Ans. : d]

Q.139 What is the percentage of contribution of cavitation to the total material removed ?

a <5%
b 5 - 10 %
c 10 - 20 %
d 20 - 50 %
[Ans. : a]

Q.140 In the following mechanisms, which one is dominant in material removal ?

a Hammering
b Cavitation
c Microchipping
d None of the mentioned
[Ans. : a]

Q.141 When machining porous material, which type of mechanism is introduces ?

a Abrasion
b Erosion
c Corrosion
d Vaporization
[Ans. : b]

Q.142 The rate of material removal depends on which of the following features ?

a Frequency
b Static Pressure
c Machining area
d All of the mentioned
[Ans. : d]

Q.143 The machinability of USM depends on brittleness criterion.

a True
b False
[Ans. : a]

Q.144 Which of the following are the features of tool affecting MRR in USM ?

a Hardness
b Wearability
c Accuracy
d Mounting
[Ans. : d]

Q.145 What is the machinability rate of glass by USM ?

a 25 %
b 50 %
c 75 %
d 100 %
[Ans. : d]

Q.146 What happens to MRR with increase in tool amplitude ?

a Increases b Decreases

c Remains same d None of the mentioned **[Ans. : a]**

Q.147 The vibration amplitude determines, which parameter of the abrasive particles ?

a Force b Torque

c Velocity d Pressure **[Ans. : c]**

Q.148 If splashing occurs, it will result in an increase of material removal rate in USM.

a True b False **[Ans. : b]**

Q.149 Amplitude of the oscillation ranges between which of the following values ?

a 0.01 - 0.04 mm b 0.04 - 0.08 mm

c 0.08 - 0.10 mm d 0.10 - 0.20 mm **[Ans. : b]**

Q.150 As the vibration frequency increases, what happens to material removal rate ?

a Decreases b Increases

c Increase and then decrease d Decrease and then increase **[Ans. : c]**

Q.151 Which of the following can be used as an abrasive carrying medium ?

a Water b Benzene

c Glycerol d All of the mentioned **[Ans. : d]**

Q.152 If there is an increase in viscosity of slurry, what happens to MRR ?

a Increases b Decreases

c Remains same d None of the mentioned **[Ans. : b]**

Q.153 How much percent of the abrasives are recommended in general for abrasive medium ?

a 10 - 15 % b 15 - 20 %

c 25 - 30 % d 30 - 35 % **[Ans. : d]**

Q.154 Machining rate can be affected by the ratio of hardness of tool to that of hardness of work piece.

a True b False **[Ans. : a]**

Q.155 As the tool area increases, what happens to MRR ?

a Decreases b Increases

c Remains same d None of the mentioned **[Ans. : a]**

Q.156 When the static pressure of the feed is increases, what happens to MRR ?

a Increases b Decreases

c Increase up to a limiting condition d Decrease up to a limiting condition **[Ans. : c]**

Q.157 Which of the following distribution factors, does not affect the machining parts ?

a Side wear of tool | b Abrasive wear
c Accurate feed | d Form error of tool **[Ans. : c]**

Q.158 Which one of the following factors affects the accuracy of parts ?

a Steady abrasive flow | b Accurate feed
c Unsteady abrasive flow | d Ultrasonic frequency **[Ans. : c]**

Q.159 State whether the statement is true or false.

"Hole oversize measures the difference between hole diameter measured at the bottom surface, and the tool diameter."

a True | b False **[Ans. : b]**

Q.160 While machining W4C and glass, tool over cut size when compared to mean grain size is ?

a Two times greater | b Two times smaller
c Three times greater | d Three times smaller **[Ans. : a]**

Q.161 While machining B4C, tool over cut size when compared to mean grain size is ?

a Two times greater | b Two times smaller
c Three times greater | d Three times smaller **[Ans. : c]**

Q.162 In the following USM accuracy levels are limited to which value ?

a ± 0.01 mm | b ± 0.05 mm
c ± 0.10 mm | d ± 0.50 mm **[Ans. : b]**

Q.163 Conicity resulting after machining by ultrasonic machining can be reduced by ?

a Direct injection of slurry | b Tools having negative taper
c High static pressure | d All of the mentioned **[Ans. : d]**

Q.164 Typical roundness error in graphite, resulted due to lateral vibrations is between ?

a 01 - 20 μm | b 20 - 60 μm
c 60 - 100 μm | d 100 - 150 μm **[Ans. : b]**

Q.165 Typical roundness error in glass, resulted due to lateral vibrations is between ?

a 01 - 20 μm | b 20 - 40 μm
c 40 - 140 μm | d 150 - 250 μm **[Ans. : c]**

Q.166 Which of the following factors affect the surface finish of machined parts in ultrasonic machining ?

a Amplitude
b Material
c Tool surface
d All of the mentioned **[Ans. : d]**

Q.167 What is value of surface finish achieved, when we use the abrasive of grit number 240 ?

a 0.01 - 0.08 μm
b 0.08 - 0.13 μm
c 0.13 - 0.25 μm
d 0.25 - 0.38 μm **[Ans. : d]**

Q.168 When the viscosity of liquid carrier is increased, the surface quality of the parts ?

a Increased
b Decreased
c Remained same
d None of the mentioned **[Ans. : c]**

Q.169 Ultrasonic Machining can be used for which of the following processes and applications ?

a Drilling
b Sinking and contouring
c Polishing
d All of the mentioned **[Ans. : d]**

Q.170 What is the limit of surface area that is to be machined using USM ?

a $<100\ mm^2$
b $<500\ mm^2$
c $<1000\ mm^2$
d $<1500\ mm^2$ **[Ans. : c]**

Q.171 Drilling in ultrasonic machining is done, by which motion of the tool ?

a Only rotation
b Only oscillation
c Oscillation and rotation
d None of the mentioned **[Ans. : c]**

Q.172 In which of the following materials, rotary ultrasonic machining can be used to drill holes through them ?

a Glass
b Alumina
c Ferrite
d All of the mentioned **[Ans. : d]**

Q.173 State whether the following statement is true or false.

"Rotary Ultrasonic Machining is the process in which, interrupted drilling of small-diameter holes takes place."

a True
b False **[Ans. : b]**

Q.174 On which of the following features of cavity, will the penetration depth depend on ?

a Depth
b Diameter
c Size
d All of the mentioned. **[Ans. : d]**

Q.175 What is the value of depth in ultrasonic sinking, after which, material removal becomes difficult ?

a 1 to 2 mm
b 2 to 5 mm
c 5 to 7 mm
d 7 to 10 mm **[Ans. : c]**

Q.176 In production of EDM electrodes, typical ultrasonic speeds, in graphite ranges between ?

a 0.01 - 0.10 cm/min
b 0.10 - 0.25 cm/min
c 0.25 - 0.40 cm/min
d 0.40 - 1.40 cm/min **[Ans. : d]**

Q.177 How much is the value of surface finished, achieved using ultrasonic polishing ?

a 0.1 μm
b 0.3 μm
c 0.5 μm
d 0.7 μm **[Ans. : b]**

Q.178 In micro-ultrasonic machining, which of the following component vibrates ?

a Tool
b Work piece
c Feed pipe
d All of the mentioned **[Ans. : b]**

Q.179 In micro-USM, using WC tool, what is the value of diameter can be achieved ?

a 1 μm
b 3 μm
c 5 μm
d 7 μm **[Ans. : c]**

Introduction and Mechanical Energy Based Processes ends ….

Unit - II

Chapter - 2

THERMAL AND ELECTRICAL ENERGY BASED PROCESSES

Syllabus : Electric Discharge Machining (EDM) - Wire cut EDM - Working Principle-equipments-Process Parameters-Surface Finish and MRR- electrode / Tool - Power and control Circuits-Tool Wear - Dielectric - Flushing - Applications. Laser Beam machining and drilling, (LBM), plasma, Arc machining (PAM) and Electron Beam Machining (EBM). Principles - Equipment -Types - Beam control techniques - Applications.

2.1 Electric Discharge Machining (EDM)

Definition

EDM is the controlled erosion of electrically conductive materials by the initiation of rapid and repetitive spark discharge between the electrode tool (Cathode) and workpiece(Anode) separated by a small gap of 0.01 to 0.05 mm, kept in a bath of dielectric medium.

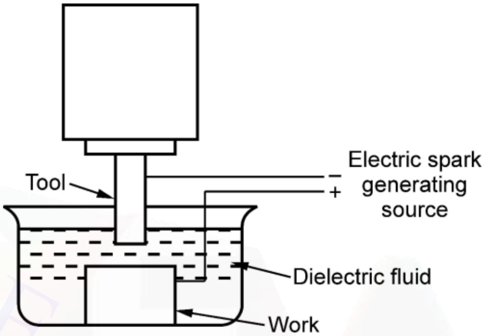


Fig. 2.1 EDM Process

2.1.1 Equipment

The important elements of the EDM process equipment are,

1. **Work-piece -** All the conductive material can be worked by EDM.
2. **Tool electrode -** The EDM electrode is the tool that determines the shape of the cavity to be produce.
3. **Dielectric fluid -** The EDM setup consists of tank in which the dielectric fluid is filled. Electrode and workpiece submersed into the dielectric fluid.
4. **Servo system -** The servo system is commanded by signals from gap voltage sensor system in the power supply and control the feed of electrode and workpiece to precisely match the rate of material removal.
5. **Power supply -** The power supply is an important part of any EDM system. It transform the alternating current from the main utility supply into the pulse direct current (DC) required to produce the spark discharge at the machining gap.
6. **The DC pulse generator** is responsible for supplying pulses at a certain voltage and current for specific amount of time.

2.1.2 Dielectric Fluid

Functions of Dielectric Fluid

1. It acts as a spark conductor concentrating the energy to a very narrow region
2. It acts as a coolant for the workpiece and the tool
3. It acts as an insulating medium during the charging time of the sparking circuit in order to discharge an effective spark for machining.
4. It acts as a coolant in quenching the spark and helps arching to be prevented.
5. It acts as a flushing medium for the disposal of the product of machining.

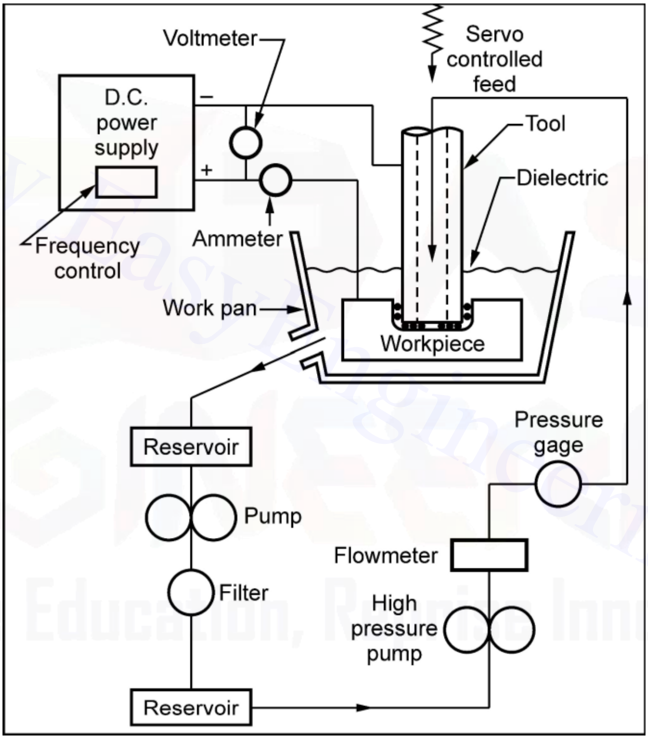


Fig. 2.2

Basic requirement of an ideal dielectric fluid

1. Should have a stable dielectric strength to be electrically nonconductive till the required discharge voltage is built up and should thereafter break down in a very short span of time.
2. It should have an optimum velocity, because a high viscosity of the dielectric results in a poor flow of dielectric in the gap between the tool and workpiece. A low viscosity dielectric is not able to carry the products of machining.

3. It should have high flash point to avoid any fire hazard.
4. It should be chemically stable at high temperatures and neutral, not to attack the electrode, workpiece, the table or the container.
5. It should not emit any toxic vapors or unpleasant odour.
6. It should be cheap and easily available.

Notes : The various dielectric fluids used are hydrocarbon oils such as kerosene, silicon oils, de-ionized water, transformer oil, white spirit, paraffin oil and polar liquids such as aqueous solution of ethylene glycol.

- De-ionized water rarely used because it results in high electrode wear. But it enhances high MRR and better cooling capacity.
- White spirit is used for machining small part with intricate details. Also it is used to machine tungsten carbide.
- Choice of dielectric depends on
  - Size of the workpiece
  - Shape complexity
  - Tolerance surface finish
  - Material removal rate
- The dielectric is pumped and kept in circulation during the machining, so as to avoid non-uniform machining and ensure surface quality which is intended.

2.1.3 Tool

- The purpose fi the tool in EDM process is to convert the electrical discharge pulse to the workpiece to allow erosion of the workpiece at the required rate.

Desirable characteristics of the tool material

- High thermal conductivity
- High electrical conductivity
- High melting temperature
- Cheap and easily machinable

- The selection of tool material depends on
  1. The wear ratio of the tool

     It is the ratio of the loss of tool material is given time to the volume of metal removed from the workpiece in the same time. The less the wear ratio, the better is the tool material.

2. The hardness of the tool

   Though material of any hardness may be used as an electrode the softer the tool material the more will be the tool wear.

3. Tolerance of the workpiece

   The required tolerance on the workpiece can only be obtained, when the tool wear ratio is low.

4. Ease of shaping the tool electrode.

   For precision manufacturing harder materials are selected which emposes difficulties in shaping the tool.

5. The surface finish of the machined workpiece.
6. Total volume of the material to be removed.
7. Nature of the dielectric fluid.

2.1.4 Tool Materials

1. **Metallic Materials**

   Electrolytic copper, Tellurium or Chromium Copper, Copper Tungsten, Brass, tungsten, Steel, Zinc, Zinc Alloys, Tunsten Carbide and Aluminium.

2. **Non-Metallic Materials** – Graphite
3. Combination of metallic and non-metallic- Copper Graphite.

Copper and brass are the two commonly used tool materials since it satisfies all the requirements but exhibits high wear rate.

Copper tungsten	Less wear ratio, able to produce good surface finish. Difficulty in machining intricate shapes.
Tungsten carbide	Difficult to machine to the required shape or profile.
Graphite and copper graphite	Easily machined and available in various grades. Drawback – its brittleness.

- The advantages of graphite electrode.
  1. It is not affected by thermal shocks.
  2. It has relatively high melting point and also chemically stable.
  3. Easily machinable by simple conventional methods.
  4. Offers low cost of operation.
- Aluminium is used as an electrode because of its high thermal and electrical conductivity. It also high machinability which enables it to be shaped to any profile.

2.1.5 Work Materials

- Work materials of any hardness value, which is electrically conductive can be processed by EDM.
- On the reasons of economy, normally hard materials are machined by employing EDM process. Refractory materials, hard carbides and hardenable steels also can be machined.

2.1.6 Servo Mechanism

- EDM machines are equipped with a servo control mechanism that automatically maintains a constant gap of about the thickness of a human hair between the electrode and the workpiece.
- It is important because, that there is no physical contact between the electrode and the workpiece, otherwise arcing could damage the workpiece and break the wire in case of wire EDM.
- The servomechanism advances the electrode into the workpiece as the operation progresses and senses the work-wire spacing and controls it to maintain the proper arc gap which is essential to a successful machining operation.

2.1.7 Electrode Feed Control

- Since, during operation both workpiece and electrode are eroded, the feed control must maintain a movement of the electrode towards the workpiece at such a speed that the working gap, and hence, the sparking voltage remains unaltered.

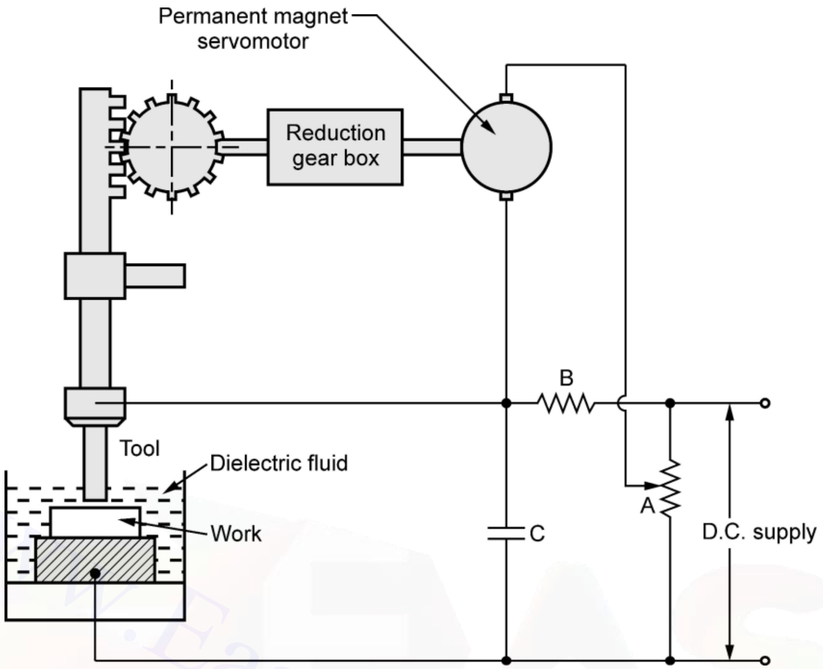
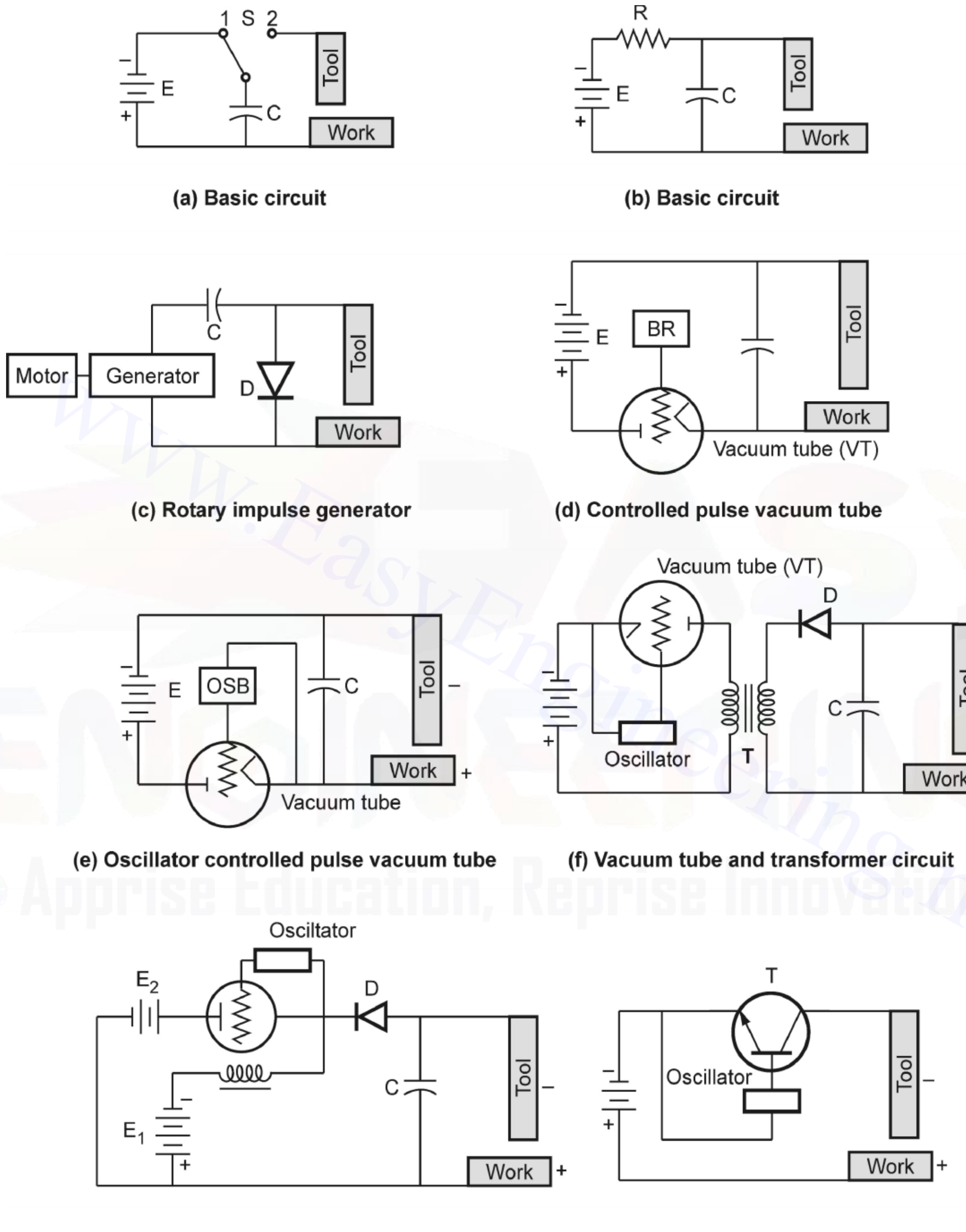


Fig. 2.3

2.1.8 Spark Generator and Electrical Circuitry

- The power supply is an important part of EDM system. It transforms the AC into a pulsed DC which is required to initiate and maintain the unidirectional spark discharges at the machine gap.
- **The functions of a spark generator** in an EDM circuit are,
  1. To supply the required voltage , for the machining discharge
  2. To control the discharge duration
  3. To have a control over the discharge current density
  4. To control the discharge cycle
- Most EDM power supply circuits convert the input AC into DC power by employing conventional solid state rectifier. In all EDM circuits, a capacitor is used for storing the electric charge before the discharge takes place across the gap.
- To achieve the different functions, different power supply circuits are used. They are
  1. Relaxation Circuit (RC) or Resistance Capacitance Circuit or RC circuit.
  2. Rotary impulse generators
  3. Controlled pulse circuit.

2.1.8.1 Relaxation Circuit or Resistance - Capacitance Circuit



(a) Basic circuit

(b) Basic circuit

(c) Rotary impulse generator

(d) Controlled pulse vacuum tube

(e) Oscillator controlled pulse vacuum tube

(f) Vacuum tube and transformer circuit

(g) Vacuum tube (two power source)

(h) Transisted pulsed circuit

Fig. 2.4 Types of power supply

- It is one of the oldest and simplest generator to initiate the spark. This generator supplies current to a condenser, the discharge from which produces the spark. The R-C circuit operates on the principle of self-oscillation.
- When the power supply is switched on, the condenser charges through the resistance R. The voltage across the gap V varies with time according to the relation

$$V = V_s (1 - e^{-t/re})$$

Where,

V_s = The source voltage or supply voltage

T = The time starting at the instant V_S is applied

- First the value of V keeps on rising till it approaches the voltage which is sufficient to breakdown the dielectric medium. The voltage at this point is termed as discharge voltage.
- The discharge time is much smaller than the charging time.
- The spark frequency (γ) is approximately given by the following equation.

$$\gamma = \frac{1}{tC} = \frac{1}{RC \text{ Log } \frac{V_s}{V_s - V_d}}$$

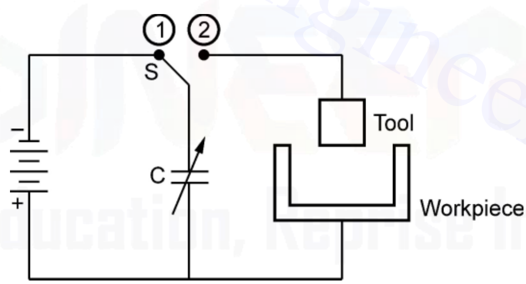


Fig. 2.5 Basic circuit of spark generator

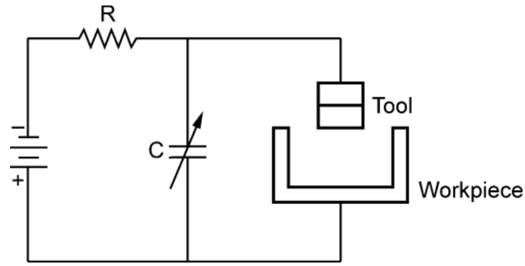


Fig. 2.6 RC circuit

- Where, t_c is the charging time which is the time required for the gap voltage to reach a value V_d.

- The pulse generator circuit can produce high energy sparks whose frequency ranges from 3000 to 10000 per second.
- In this circuit metal removal rate largely depends on high amperage and capacitance.
- An increase in supply voltage means increase in energy liberated per pulse. But this also results in longer charging cycle and lowering of process efficiency.
- The rate of charging of the condenser is influenced by the capacitance (C) and resistance(R).
- This type of circuit is simple, rugged, cheap and reliable in construction. It is best suited for large amount of metal removal rate where critical surface finish is not desired.

2.1.8.2 Rotary Impulse Generator

- It supplies the voltage wave form based on the principles as in the case of DC generators. The rotary impulse generator eliminates the disadvantages of the relaxation circuit. This generator is used for increasing MRR.
- This circuit consists of a rectifier to convert the AC into DC and a pulsar to initiate DC pulses or unipolar pulses.
- The capacitor in this rotary impulse generator is charged through a diode during the first half cycle of the AC input. In the next half cycle, the sum of the voltages generated by the generator and the charged capacitor is applied to the work-tool gap.
- The operating frequency of the generator depends on the motor speed. This generator circuit produces high MRR but poor surface finish.

2.1.8.3 Controlled Pulse Generator

- These generators consists of electronic switching units which allow the current to pass periodically and to effectively control the parameters of the machining.
- This generator circuit also prevents current flow when a short circuit is developed. To achieve this a transistor is used as a switching device.
- A high frequency and a maximum amperage at that frequency results in optimum metal removal rate, with better surface finish. But a high frequency and low amperage setting results in excellent surface finish. Roughing application can employ low frequency discharges.

Notes : High frequency and maximum amperage gives better surface finish, whereas high frequency and low amperage gives poor surface finish.

- In the controlled pulse generator circuit, current flows through the gap from the capacitor during sparking.

- The transistor attached in the circuit behaves as an infinite resistance, by getting biased. When the current in the gap ceases, the conductivity of the tube increases, allowing the flow of current to charge the capacitor for the next cycle.
- An oscillator if employed in the circuit will help to control the biasing and allow the current to flow cyclically with an imposed frequency and increased stability.

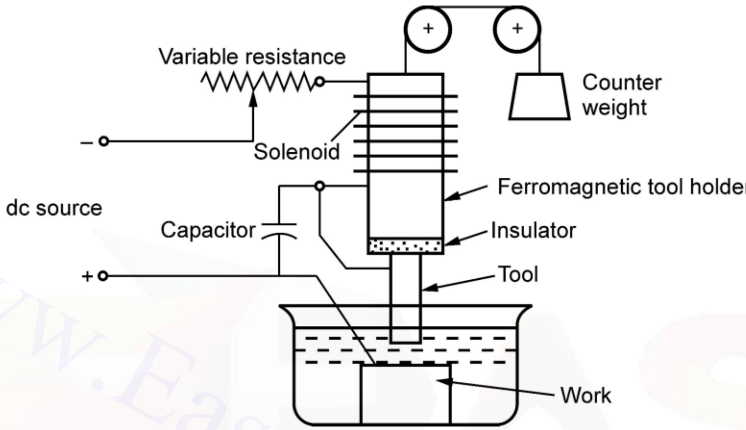


Fig. 2.7 Slenoid controlled EDM

- Advantages of pulse controlled generators.
  1. Tool wear is greatly reduced.
  2. Better surface finish
  3. No. of spark per second produced is high which reduces the machining time.

2.1.9 Working Principle of EDM

- The EDM process involves the removal of work material by finite discrete periodic sparks between tool and the conductive work material separated by a thin film of dielectric medium.
- When two electrodes connected to a DC power source are separated by a very small gap, spark occurs between the two electrodes at the point of closest contact.
- Workpiece is connected to a positive terminal of the DC power supply and negative is connected to a tool.
- In EDM tool shaped to the mirror image of the cavity to be produced.
- The tool and the work are kept immersed in a dielectric medium to promote the effectiveness of the process.

- When the voltage across the gap becomes sufficiently larger (more than 250 V) the high power spark is produced. So, the dielectric breaks down and electrons are emitted from the cathode (Tool) and the gap is ionized.
- This spark occurs in an interval of 10 to 30 micro seconds and with a current density of 15 - 500 A per mm^2 approximately. So thousands of spark discharge occur per second across the gap between the tool and the work. Which results in increasing temperature of about 10000° C
- At this high temperature, work piece metal is melted, eroded and some of it is vaporized. In this way the metal is removed from the work piece.
- The removed fine material particles are carried away by dielectric fluid circulated around it.
- Particles eroded from the electrodes are known as Debris.
- When the two electrodes are of the same material, the positive terminal is eroded at a faster rate than the negative one.

2.1.10 Mechanism of Metal Removal

- When a suitable voltage is applied between the work and the tool, an electrostatic field of sufficient strength is established and due to this cold emission of electrons starts from the cathode.
- These electrons from the cathode accelerate towards the anode. These electrons while travelling towards the anode collide with the molecules of the dielectric fluid breaking them into electrons and positive ions.
- The electrons so produced also accelerate towards the anode and also dislodge other electrons from the dielectric medium during their travel.
- This process leads to the formation of a narrow column of ionized dielectric molecules between the tool and workpiece.
- This ionized column of ions, have high conductivity, is the spark. This spark occurs at the place of closest contact between the tool and workpiece surface, producing very high temperature on the electrodes.
- This high temperature melts and vaporizes the positive electrode at the spot of spark formation and the compression shock wave generated evacuate the molten metal by mechanical blast, thus removing material.
- When the material is thus removed the spark gap at that particular spot increases and the cycle is repeated at the place of next shortest gap.

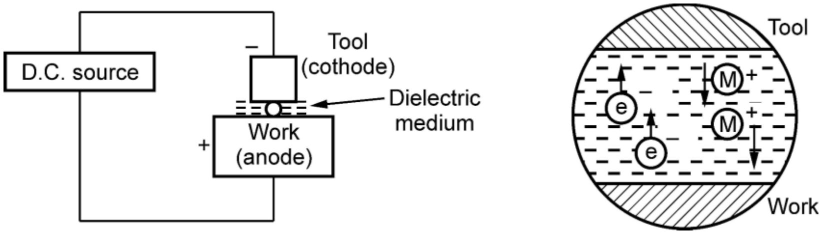


Fig. 2.8

- When the above process is taking place in the equipment, yet another phenomenon occurs in the electrical circuit.
- When the supply voltage is given to the circuit, since the dielectric as it is, is a non-conductor does not allow the current to flow through the gap. So a major part of the applied voltage is stored in the condenser for further recharge.
- A minor portion of the applied voltage causes the cold emission of electrons from the cathode.
- When dielectric medium is fully ionized it becomes a conductor and the entire stored voltage in the capacitor is discharged from the cathode to anode which removes the material.

2.1.11 Material Removal Rate

- The amount of material removed in a single discharge can be determined by considering the diameter of the crater and the depth to which melting temperature is reached.
- Assumptions considered for the theoretical calculation of MRR are
  - The properties of the electrode material do not change with the increase of temperature.
  - The rate of heat input is a constant throughout the discharge period.
  - The vaporization of the electrode material is neglected.
  - The spark is a uniform circular column heat source and the diameter of the column is also a constant.
  - The regions other than the heat source is insulated.
- MRR increases with an increase in discharge duration for different spark energies, but up to a certain limit and then drops to zero. It is also observed that the MRR is maximum when the pressure is below atmospheric.
- The MRR is also strongly influenced by the circulation of dielectric fluid, without a forced circulation, the wear particles melt and reunite with the electrode.

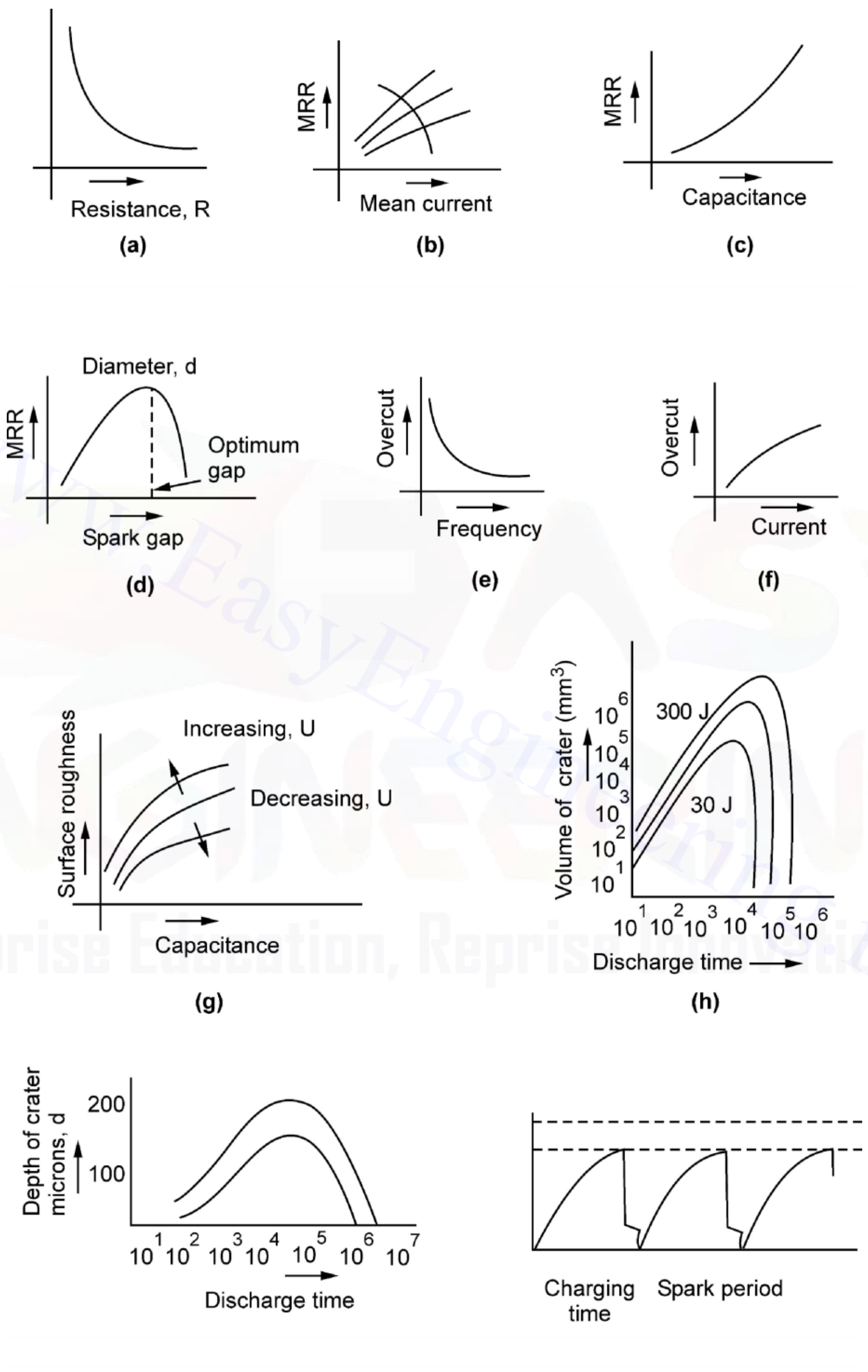


Fig. 2.9 Graphical representation of various process parameters

- The MRR is proportional to the working current. (Working current is the volume of metal removed per unit time per ampere). As the current increases, the energy of spark increases and hence the MRR.
- A higher pulse energy increases MRR but results in a bigger size of broken off or machined particles.
- For a particular electrical parameter, there is an optimum machining at which the MRR is high, lower the electrical conductivity of a work material, lower will be the MRR.
- The viscosity of the dielectric medium also influences the MRR. Lower is the viscosity of the dielectric, lesser will be the amount of eroded particle carried away which would affect the MRR.
- The metal removal rate increases with the decrease in the resistance for a particular value of capacitance. However, the resistance is decreased below a particular value would in arching and damage the work.

2.1.12 Expression for Material Removal Rate (MRR)

- The MRR in EDM is basically a function of the current and the melting point of the workpiece material, although other process variables also have an effect. The following approximate empirical relationship can be used as a guide to estimate the MRR in EDM.

$$\mathbf{MRR = 4 \times 10^{4}\ I.T_W^{-1.23}\ mm^3}$$

$$I = \text{Current in ampere}$$

$$T_W = \text{Melting point of the workpiece in °C}$$

2.1.13 Tool Electrode Wear

- During the EDM operation not only the work material (Anode) is eroded but also the cathode due to sparking.
- **The wear ratio is the ratio of the materials removed from the work materials to material removed from the tool**

$$\text{Wear ratio} = \frac{\text{Materials removed from the work materials}}{\text{Material removed from the tool}}$$

- Normally electrode wear at the end of corner or at all the sides. The electrode wear is basically function of polarity, thermal conductivity, melting point of electrode, duration and intensity of spark discharges and the type of work material used in connection with the tool material.
- The knowledge of the tool wear is important while designing the tool electrode and the selection of tool for a particular application.

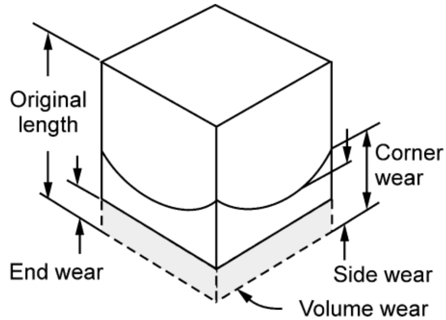


Fig. 2.10

- The wear rate of the electrode w_t, can be estimated from the empirical equation:

$$w_t = 1.1 \times 10^{11} \; I.Tt^{-2.38} \; mm^3 / min.$$

where, T_t is the melting point of electrode material

The wear ratio of the workpiece to electrode, R can be estimated from the expression

$$R = 2.25 \; T_r^{-2.38}$$

where, T_r is the ratio of workpiece to electrode melting point.

2.1.14 Accuracy and Surface Finish

- The accuracy and the surface finish in EDM is depends on the diameter and depth of the crater formed due to the spark. If the size of the crater is large, then the surface finish obtained is rough.
- The greatest factor responsible for inaccuracy in the EDM process is the formation of side sparks between the tool surface and the machined work piece. The side sparks remove extra material from the machined surface and enlarges the cavity or hole.
- Higher value of capacitance leads to greater pulse energy and hence bigger particles of material removal.
- If the machining area is more, larger is the inaccuracy.
- Lesser the tool wear ratio greater will be the inaccuracy.
- Increase of pulse energy increase in the working voltage and leads to poor or rough surface finish.
- Forced circulation of the dielectric fluid results in improved surface finish than without forced circulation.

2.1.15 Flushing

- The circulation of dielectric fluid between the electrode and the workpiece is called flushing. Flushing is a vital for process efficiency and product quality.

- The effective flushing removes wastes products from the gap and increases MRR whereas the bad flushing results in low MRR and poor surface finish.
- The good flushing system is one that shoots the dielectric to the place where the sparking occurs. It is observed that flushing in blind cavities is difficult.
- So, flushing does not perform well in blind cavities.
- Various methods of flushing are,
    - Suction through electrode
    - Suction through workpiece
    - Pressure through electrode
    - Pressure through workpiece
    - Jet flushing
    - Periodic cycling of electrode

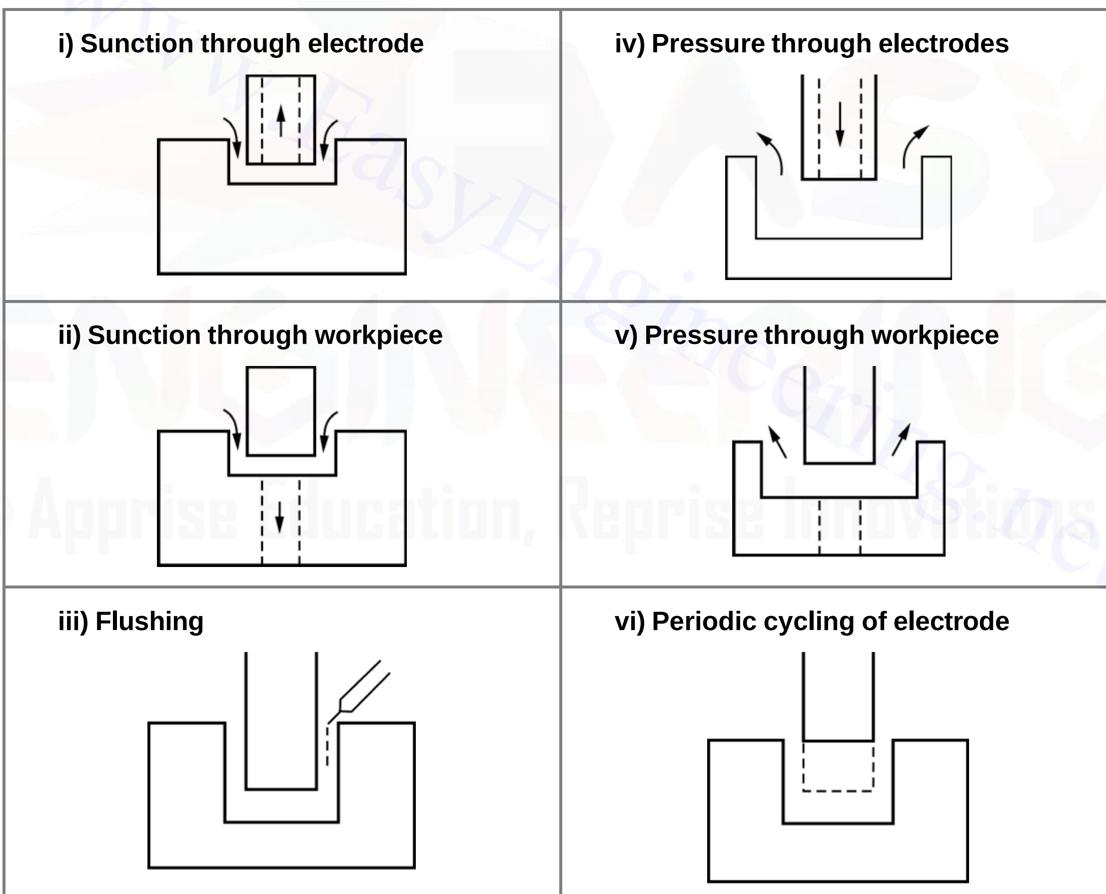


Fig. 2.11

2.1.16 Advantages

1. Any conductive materials of any hardness, toughness or brittleness can be machined.
2. Tool material property is not a constraint to restrict the machining.
3. No cutting forces is encountered since there is no contact between tool and workpiece.
4. Thin sections also can be machined.
5. Complicated geometrical forms can be easily reproduced.
6. High accuracy is possible.
7. It is a burrless process.
8. Materials can be machined even in the heat treated condition.
9. Surface finish obtained is good.
10. More suitable for producing surfaces that are to be used for wear resistance which can contain lubricant.

2.1.17 Disadvantages

1. Low material removal rate (MRR)
2. Thermal stress may develop due to intense heat.
3. Power required is very high.
4. Possibility of surface cracking is encountered in some materials
5. Difficult to produce soft corners.

2.1.18 Limitations

1. Only electrically conductive material can be machined.
2. Tool wear affect the accuracy and surface finish.
3. Produces heat affected zone(HAZ) in the work material.
4. High specific energy consumption.

2.1.19 Applications

1. Chiefly employed for the manufacture and reconditioning of press tools, forging dies, extrusion dies and moulds for the injection moulding.
2. Any intricate shapes or profiles on alloy steel, tungsten carbide dies can be produced with fine details.
3. Blind complex cavities micro holes for nozzles and fuel injectors through cutting of non-circular holes and narrow slots can be produced.
4. Used for machining fragile work pieces.

5. Fine slits can be made by using a wire electrode.
6. Fine cutting can be obtained using thread shaped electrode.
7. Hole as small as 0.1 mm in diameter can be drilled.
8. Embossing and engraving operations is also possible using this process.
9. Stamping and wire drawing dies can be produced by this process.
10. Punches and forming dies are manufactured by this process.
11. Internal threads and internal helical gears can be cut in hardened materials by employing rotary spindle and suitable attachments.
12. Curved hole drilling and deep trepan drilling can also be done by this EDM process.
13. Die-sinking, cutting, slicing using a rotary disc or ribbon, external and internal form grinding are some more operations that can be performed using EDM process.

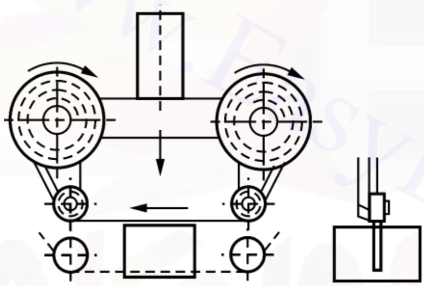


Fig. 2.12 Fine cutting with thread shaped electrode

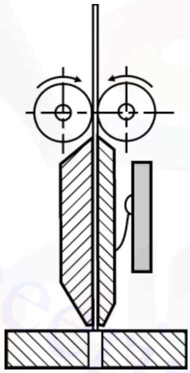


Fig. 2.13 Drilling of micro holes

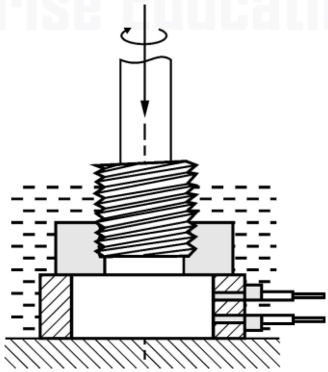


Fig. 2.14 Thread cutting

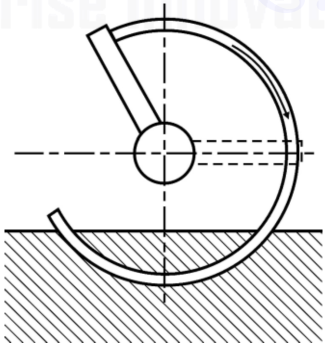


Fig. 2.15 Curved hole drilling

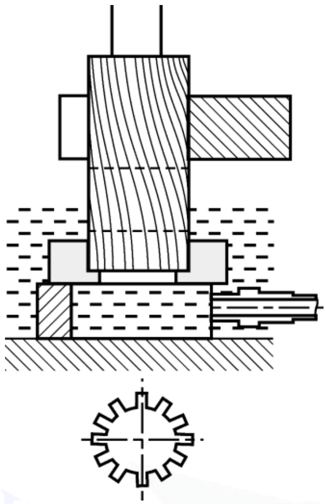


Fig. 2.16 Hellical profile drilling

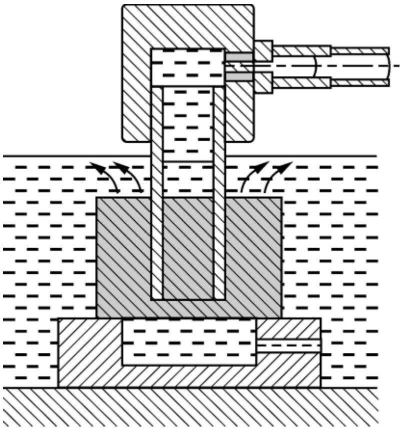


Fig. 2.17 Deep trepan drilling with injection of dielectric but without electrode rotation

- **Factors to be considered while selecting EDM machine tool** are tolerance and surface finish, power requirement, material removal rate, cost, efficiency, tooling and fixtures, tool consumption, safety, work material, and shape feature.

2.2 Electrical Discharge Wire Cutting (EDWC) or Wire EDM

- The EDWC process uses the same principle of EDM process for material removal.
- The EDWC process differs from the EDM process in the sense that it uses a thin wire to spark erode the workpiece in a complex 2D or 3D profile.
- The prominent feature of a moving wire is that, any complicated profile can be easily machined without using a forming electrode.
- This EDWC process can also be called as travelling wire EDM or Wire EDM.

Definition

- The EDWC is a material removing process in which a thin wire is used along with a stream of dielectric fluid for facilitating spark erosion.

2.2.1 Equipment

This process consists of the following elements,

1. Wire driving system	2. Positioning system
3. Power supply system	4. Dielectric system

2.2.1.1 Wire Driving System

- The EDWC removes material by using a wire electrode which is moved along the required profile or shape. The function of wire driving system is to continuously feed the wire under constant tension to the work area.
- The tensioning of the wire avoids problems that occur during machining such as taper, machining streaks, wire breaks, vibration markings.
- The wire in this process is fed from a spool, through several stages of preparation system which ensures wire straightness.
- Before the wire is passed through the workpiece, it is guided by set of rollers made of sapphire or diamond. But before being collected by the take up spool, it passes through a series of tensioning rollers.
- Some machine uses devices for wire drawing and annealing to enable direct use of the available commercial grade wires.
- When the wire passes through the workpiece, a major portion of the spark discharges occur at the leading surface of the wire, which results in the deformation of the wire cross section and so the wires is discarded after single use.

Notes : Copper, brass, tungsten and molybdenum are the materials used as wire electrode.

- The diameter of the wire electrode ranges from 0.076 mm to 0.3 mm. The normally used size of the electrode wire is 0.2 mm. The size is decided on the basis of the desired kerf width.
- **Kerf width** is one of the important performance measures in WEDM. Kerf width is the measure of the amount of the material that is wasted during machining. It determines the dimensional accuracy of the finishing part.

2.2.1.2 Positioning System

- The EDWC positioning system consists of a CNC table which may be two axis or multi axis, depending on the shape of the profile.
- **The spark gap is maintained at the required value between the workpiece and the wire electrode by connecting the positioning system to adaptive control mode.**
- This mode enables the positioning system to avoid short circuiting, if in case any machined material comes between wire electrode and the workpiece.

2.2.1.3 Power Supply System

- There are differences between the conventional EDM and the EDWC power supply system. The most differences are the frequency of the pulse and the current.
- To obtain a smooth surface finish, high frequency pulses are used in EDWC.
- Since the diameter of the wire used is small, current rating less than 20 Amps is only supplied.

2.2.1.4 Dielectric System

- Deionized water is normally used as the dielectric fluid because of its low viscosity to enter into the smaller gap, high cooling rate, high MRR and no fire hazard.
- The dielectric fluid is delivered through a nozzle to the machining area coaxial with the wire. The de-ionized water is used once is filtered with filter paper and reused again.

2.2.2 Working Principle of EWDC

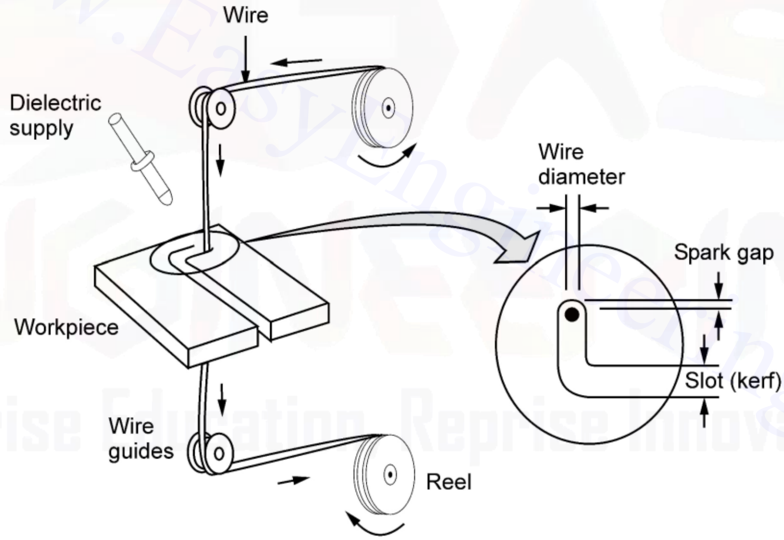


Fig. 2.18

- **EDWC** uses the thermal energy produced by the spark for removing the material. The work material is connected to the positive terminal and the wire electrode to the negative terminal of the high frequency pulses of DC power supply, which are separated by the spark gap.
- The spark gap is fed with the supply of dielectric fluid.
- When the power supply is switched on spark appears in the gap and the work material is machined by the intense heat which melts and vaporizes it.

- The wire is continuously fed from spool through the guiding rolls and taken up by the take up rolls.
- The machine table is moved along with the workpiece along the profile in which it need to be machined.

2.2.3 Material Removal Rate

- The MRR for wire EDM can be obtained from the following expression,

$$MRR = V_f h.b$$

V_f = Feed rate of the wire into workpiece in mm/min.

h = Workpiece thickness or height in mm. and, the kerf is denoted as d_w+2s

dw = Wire diameter in mm.

S = Gap between wire and workpiece during machining in mm.

2.2.4 Advantages

1. No fabrication of electrode is required.
2. No cutting force are encountered.
3. Can machine any hard material.
4. Automation is possible.
5. Electrode wear is negligible.
6. Machined surfaces are smooth.
7. Extremely high tolerances can be achieved.
8. Any profile or shape can be obtained through this process.

2.2.5 Disadvantages

1. High capital cost.
2. Formation of thin recast layer
3. Slow cutting rate
4. Applicable only in small parts.
5. Wire electrode cannot be reused which calls for high cost of electrode.

2.2.6 Applications

1. Best suited for the production of extrusion dies, Blanking dies and punches. Press tools and sintered compacting dies.

2. Can be used for shallow cutting, finishing operations and micro-drilling of non-conducting materials.
3. Thick sections of 200mm can be used machined.
4. The machining of hard press-stamping dies can be easily done.
5. Even heat treated materials can also be processed by this process.
6. Stator, core-stamping dies are machined by wire-EDM.
7. The powder compaction dies which are more thicker than normal dies, with high aspect ratios can be machined easily.
8. Even EDM electrodes can be made by this EDWC process.
9. Fabrication of grinding wheel form tools, profile gauges and templates are possible.
10. Large quantities of parts can be cut simultaneously by arranging them into a stack.

2.2.7 Difference between EDM and Wire Cut EDM

S. No	Wire cut EDM	EDM (Die sinking)
1.	Thin wire is used as a tool	Shaped tool is used. (Mirror image of the workpiece)
2.	Very thin wire made of brass or molybdenum is used as the electrode (tool).	Expensive alloy of silver and tungsten are used as the electrode (tool) which are traditionally made by cutting and grinding.
3.	The whole workpiece is not submerged in dielectric medium. Instead, the working zone alone is supplied with a co-axial jet of dielectric medium	The whole workpiece is submerged in dielectric medium
4.	It is easy to machine complex two dimensional profiles.	It is difficult to cut complex two dimensional profiles.

2.3 Laser Beam Machining (LBM)

Laser is the term applied for phenomenon of amplification of light by stimulated radiation emission.

2.3.1 Construction

- Fig. 2.19 shows the setup of laser beam machining, which consists of a stimulating light source (Xenon flash lamp) and a laser rod.

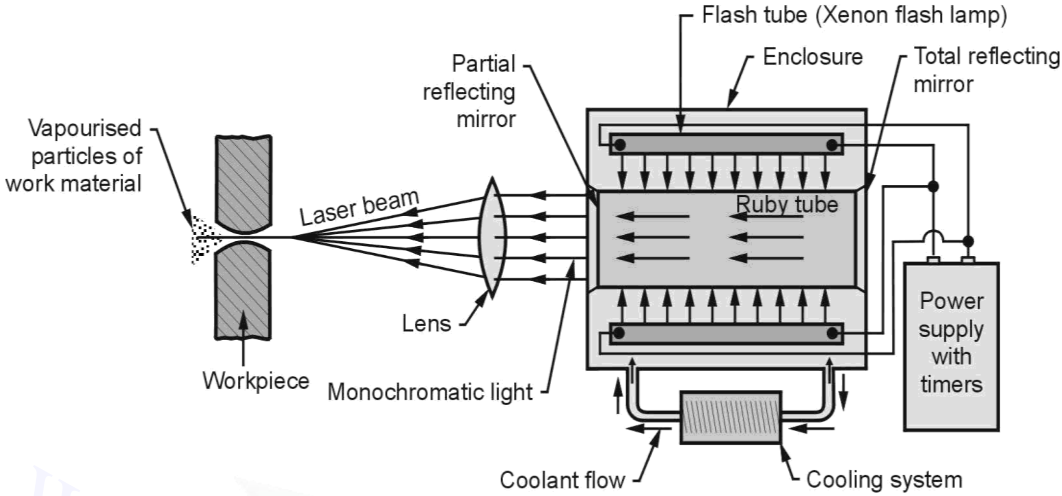


Fig. 2.19 : Laser beam machining

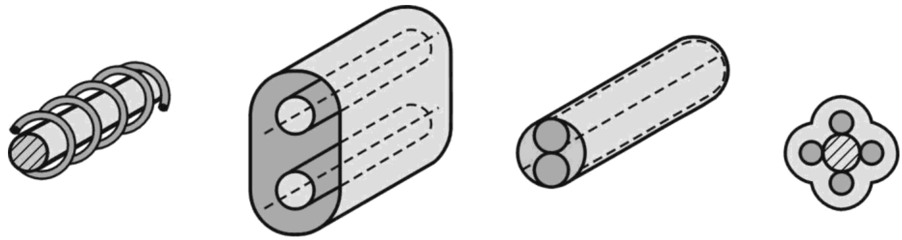
- Laser rod or laser tube consists of a pair of mirrors, which are placed at each end of a tube.
- Setup also consists of a flash tube /lamp (energy source), laser, power source, focussing source (lens) and cooling system.
- The whole setup is fitted inside an enclosure which has highly reflective surface inside it.
- The laser used in the process may be solid, liquid or gaseous type. The solid type carries reflective coatings at their ends and gaseous type produces continuous laser beams and is suitable for welding and cutting operations. Most commonly used laser is **Ruby**.

2.3.2 Working

- In operation, the optical energy (light) radiated from the flash lamp is focussed on the laser rod (tube), from where it is reflected with the help of mirrors and accelerated in its path.
- The reflected light is emitted in the form of a slightly divergent beam.
- A lens is placed in the path of this beam of light which converges and focuses the light beam on the component to be machined (workpiece).
- This impact of laser beam on the component melts the work material and due to this it vaporises. Hence it is also called as **thermal cutting process.**

2.3.3 Laser Machining System

Fig. 2.20 shows the different types of laser machining systems.



(a) (b) (c) (d)

Fig. 2.20 : Laser machining systems

- Fig. 2.20 (a) is a spiral flash lamp in which a ruby rod is kept inside the lamp.
- Fig. 2.20 (b) shows a straight flash lamp and cylindrical mirror with elliptical cross-section.
- Fig. 2.20 (c) is another laser machining system in which circular reflecting cylinder is shown.
- Fig. 2.20 (d) shows four flash lamps arranged around the ruby rod.

2.3.4 Advantages of LBM

- In LBM process there is no direct contact between the tool and workpiece, hence tool wear does not exist.
- Easy machining of brittle, non-metallic and hard materials.
- Machining can be done in any environment.
- Extremely small holes can be drilled easily.
- Refractory materials can be easily worked.
- Also used for welding of dissimilar metals.

2.3.5 Disadvantages of LBM

- LBM is applicable only for thin sections and where a small quantity of material is removed.
- Holes drilled may have a slight taper formation, hence not suitable for large holes.
- Control of hole size is difficult.
- Safety precautions and procedures are to be followed.
- Durability and reliability of the system is limited.
- Limited life of flash lamp leads high operational cost.
- Initial cost and operating cost of system is quite high.
- Due to low production rate, efficiency of the system is low.
- Highly skilled operators are required.

2.3.6 Applications of LBM :

- LBM is mainly used for trimming of sheet metal, carbon resistors and plastic parts.
- It is used for drilling small holes in materials like tungsten, ceramics which are very hard.
- Cutting complicated profiles on thin films for making ICs (Integrated Circuits), engraving patterns on thin films LBM is used.
- LBM is also suitable for dynamic balancing of precise rotating components like watches.

2.4 Electron Beam Machining (EBM)

2.4.1 Principle :

- EBM process is used for machining of materials using high velocity beam of electrons. The component to be machined (workpiece) is held in vacuum chamber and beam of electrons is focused on to it magnetically.

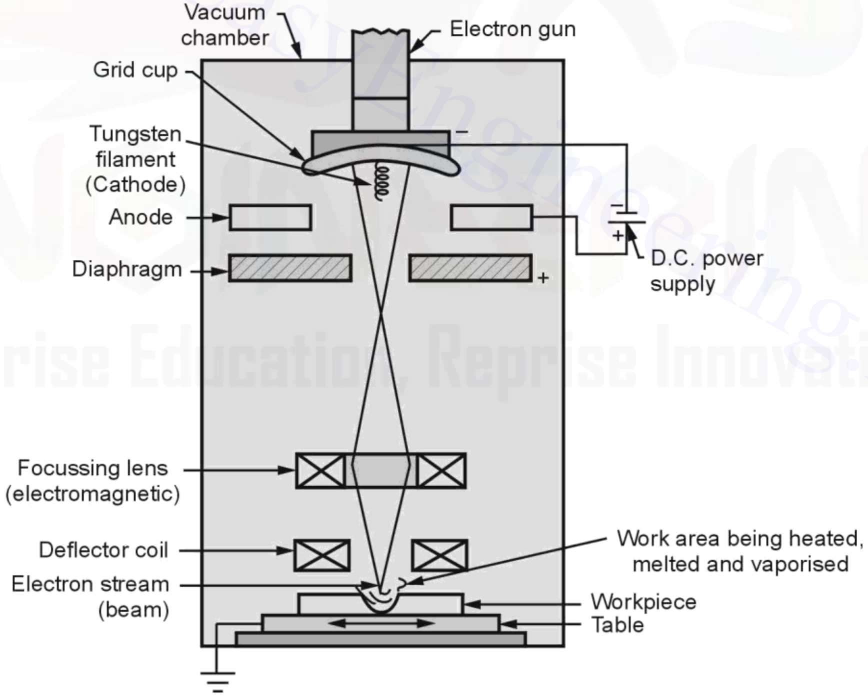


Fig. 2.21 : Electron beam machining

- When electrons strike the workpiece their kinetic energy is converted into heat energy and raises the temperature of workpiece. Due to high temperature, a small amount of workpiece material vaporises that means there is removal of metal from the workpiece.

2.4.2 Construction

- Fig. 2.21 shows the set up for Electron Beam Machining. The complete setup is enclosed in a vacuum chamber having vacuum of order 10^{-5} mm of Hg.
- The vacuum chamber carries a door, through which the component to be machined (workpiece) is placed on the table. After placing the component the door is sealed.
- The electron gun which is the main cause of emission of electrons consists of three main parts :

  (a) Tungsten filament (b) Grid cup (c) Anode.
- Tungsten filament acts as a cathode, as it is connected to negative terminal of D.C. supply and positive terminal is connected to anode as shown in Fig. 2.21.

2.4.3 Working

- As the current supply starts, the filament wire is heated to a temperature upto 2500°C in the vacuum. Due to this, electrons are emitted by filament, which is directed by the grid cup to travel downward.
- A potential difference of 50-150 kV is maintained between anode and filament. The velocity of electron passing through anode is 2/3 of light.
- This high velocity electron stream after passing through anode passes through tungsten diaphragm and then through the electromagnetic focussing coil.
- After passing through focussing coil (focussing lens) it precisely focus on the desired area of the component.
- The workpiece is kept on the table which can be traversed as per the requirement.
- When the high velocity beam of electrons impact on the workpiece, its kinetic energy is converted into heat energy.
- Due to high temperature, generated (heat) material from the workpiece is removed by vaporisation.
- Melting and vaporising of the metal takes only a fraction of second and turning off of the beam is necessary to conduct away the heat from the workpiece.

Need for vacuum :

- The electron beam should not collide with the molecules of gas and should not scatter.
- Electrons can travel from cathode to anode easily.
- There should be no loss of heat from cathode.
- To maintain high velocity of electron beam i.e. 2/3 of light.

2.4.4 Advantages of EBM

- Accurate and precise holes can be machined.
- It is a quicker process i.e. 1 hole in 1 second.
- Small diameter, narrow slots can be easily machined.
- It can machine any material i.e. metal or non-metal.
- Close dimension tolerances can be machined, as there is no tool wear as in case of EDM.
- There is no direct contact between tool and workpiece, hence damage of workpiece surface is avoided.
- It is a good technique for micro-machining.

2.4.5 Disadvantages of EBM

- Perfectly cylindrical deep holes can not be produced.
- High power consumption.
- As the process takes place in vacuum chamber and size of the chamber is limited, workpiece size is also limited.
- MRR is low.
- Initial investment is high.
- Highly skilled operator is required for the operation.

2.4.6 Applications of EBM

- EBM is used for producing precise holes in wire drawing dies.
- Used for machining operations like cutting, drilling or milling on varieties of materials, irrespective of hardness.
- Also suitable for micro-drilling operations (upto 0.002 mm) for thin orifices, injector nozzles for diesel engines.
- Also used for synthetic jewels drilling in watch industry.

2.5 Plasma Arc Machining (PAM)

The gases have property that when they are heated to temperatures above 5500 °C they are partially ionised and they exist in the form of a mixture of positively charged ions, neutral atoms and free electrons. This mixture is called as **Plasma**. Central part temperature of plasma is upto 11000 °C to 28000 °C and at that temperature the gas is completely ionised.

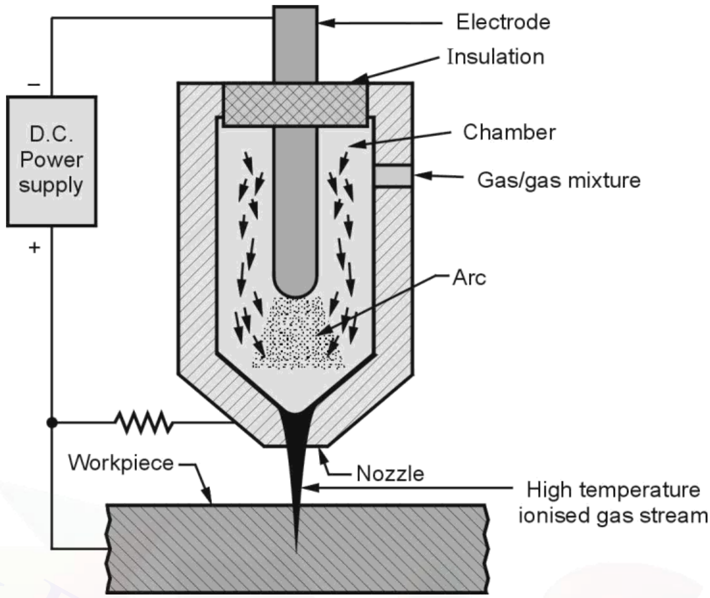


Fig. 2.22 : Principle of plasma arc machining

2.5.1 Construction

- Fig. 2.22 shows the general set-up for plasma arc machining or many times called as **Plasma Arc Cutting**.
- In this the Plasma-arc cutting torch carries an electrode which is generally made up of tungsten fitted in a small chamber.
- This tungsten electrode is connected to the negative terminal of a d.c. supply, hence acts as a **cathode** whereas positive terminal is connected to nozzle formed near the bottom of the chamber, hence acts as **anode**.
- Near the torch, small area is provided for supply of gas into the chamber. Also, while operation, electrode and nozzle should remain cool hence, water circulation is provided around the torch.

2.5.2 Working

- In PAM, as per Fig. 2.22 high velocity jet of high temperature ionised gas (plasma) is directed on the component (workpiece) surface with the help of a plasma cutting torch.
- This high velocity jet melts the metal of the workpiece and molten metal is thrown away from its path.
- The workpiece is heated due to continuous attack of electrons, which transfers heat energy of ionised gas to the work material.

2.5.3 Advantages of PAM

- PAM is a quicker process.
- A very high temperature is generated for machining.
- PAM is used to cut any metal.
- There is no contact between the workpiece and tool.
- Good surface finish and accuracy upto 5-10 microns can be obtained.
- High cutting rate upto 250-1700 m/min is available. (Gas flow rate is upto 2-10 m^3/hr).

2.5.4 Disadvantages of PAM

- As the temperature generated is very high, more precautions are required for the operator.
- Due to high temperature, work surface may undergo some metallurgical changes.
- Operator also requires protection from shielding and noise.
- Initial cost of the equipment is very high.

2.5.5 Applications of PAM

- PAM is used for profile cutting of alloy steel, stainless steel, aluminium and its alloys.
- PAM is used for turning and milling of difficult to machine materials.
- Also used for removing gates and risers from a casting.
- As PAM is also used under water, it is mostly used in shipyards, chemical industries and many times in nuclear plant also.
- PAM is used for cutting of hot extrusions.

2.6 Two Marks Questions with Answers (Part - A)

Q.1 *What is the purpose of dielectric in EDM ?*

Ans. : **Dielectric** is an important parameter in **EDM** and plays a crucial role in determining high Material Removal Rate (MRR) and surface finish during operation. The **dielectric** fluid behave as a medium which controls the electrical discharge and absorb heat during process.

Q.2 *List the applications of EDM.*

Ans. :

- **Die making :** Dies are tools used to cut or shape materials into a solid product.
- Mold Making.
- Small Hole Drilling

Q.3 *What are the properties required for dielectric fluid for EDM ?*
(Section 2.1.2 (Basic requirement of an ideal dielectric Fluid))

Q.4 *List out the limitations of EDM ?* **(Section 2.1.18)**

Q.5 *Give the product applications of EDM ?* **(Section 2.1.18)**

Q.6 *List the advantages of EDM ?* **(Section 2.1.16)**

Q.7 *What is the function of servocontrol system in EDM ?* **(Section 2.1.6)**

Q.8 *What are the types of tool materials used in EDM ?* **(Section 2.1.4)**

Q.9 *What are the types of power generator circuits used in EDM ?* **(Fig. 2.4)**

Q.10 *What do you mean by recast layer with reference to the EDM ?*

Ans. : The sparks produced during the EDM process melt the metal's surface, which then undergo ultra-rapid quenching. A layer forms on the workpiece surface defined as a recast layer after solidification

Q.11 *What are the functions of adaptive control used for EDM ?*

Ans. : The purpose of the adaptive control in an EDM sinker is to read the conditions of the EDM spark and translate these conditions into digital signals that are fed into the machine's controller. The controller translates these signals, determines the efficiency of the EDM cut and makes adjustments accordingly.

Q.12 *What are the ways of gap-flushing used in EDM ?* **(Fig. 2.11)**

Q.13 *Name any four electrode materials used in EDM process.* **(Section 2.1.4)**

Q.14 *What are the functions of dielectric fluid used in Electric Discharge Machining ?* **(Section 2.1.2)**

Q.15 *Sketch the relaxation circuit of EDM.* **(Section 2.1.8.1)**

Q.16 *State the principle of EDM.* **(Section 2.1 (Definition))**

Q.17 *Name some of the most commonly used dielectric fluids in EDM.*

Ans. : So Many different **fluids** are **used** as **dielectric** fluids. **Most** of them are hydrocarbon **fluids**, silicone-based oils and de-ionized water, kerosene oil and water with glycol.

Q.18 *State the difference between wire cut EDM and EDM.* **(Section 2.2.7)**

Q.19 *What is the principle of operation of wire cut EDM process ?* **(Section 2.2)**

Q.20 *List out the applications of wire cut EDM process.* **(Section 2.2.6)**

Q.21 *What is the purpose of vacuum chamber in EBM process ?*

Ans. : Vacuums must be used to reduce contamination, and minimize electron collisions with air molecules. Because work must be done in a **vacuum**, **EBM** is best suited for small parts. The interaction of the **electron beam** with the work piece produces hazardous x-rays, and only highly trained personnel should **use EBM** equipment.

Q.22 *Define electron beam.*

Ans. : **Electron beam**, stream of electrons generated by heat (thermionic emission), bombardment of charged atoms or particles (secondary electron emission), or strong electric fields (field emission). Electrons may be collimated by holes and slits, and, because they are electrically charged, they may be deflected, focused, and energized by electric and magnetic fields

Q.23 *In EBM, why is a high vacuum created in the apparatus?*

Ans. : The entire process occurs in a vacuum chamber because a collision between an electron and an air molecule causes the electrons to scatter and thus loose their energy and cutting ability .

Q.24 *What are the different components of EBM ?* **(Section 2.2.1)**

Q.25 *State the characteristics of a LASER beam.*

Ans. :

1. Directionality 2. Monochromaticity
3. Brightness 4. Coherence

Q.26 *What is the principle of LBM ?*

Ans. : Laser Beam Machining (LBM) is a form of machining process in which laser beam is used for the machining of metallic and non-metallic materials. In this process, a laser beam of high energy is made to strike on the workpiece, the thermal energy of the laser gets transferred to the surface of the workpiece.

Q.27 *Contrast LBM and EBM.*

Ans. :

LBM	EBM
A high intensity of beam of laser is used to supply heat for material removal.	A high intensity beam of focused electrons is use to supply heat for material removal.
It does not require any vacuum chamber	It requires vacuum chamber
There is no restrictions on workpiece size	EBM process is suitable for small components
LBM is independent of electrically conductive	Electrically conductive material only can machined.

Q.28 *What are the advantages and disadvantages of LBM ?* **(Sections 2.3.4 and 2.3.5)**

Q.29 *List any two gases used in Plasma arc machining.*

Ans. : **The used gases** are argon, helium, hydrogen or a mixture **of** these

Q.30 *What is the function of water muffler in PAM ?*

Ans. : A device that produces a covering of **water** around the plasma torch and extends down to the work surface helps in reducing smoke and noise

Q.31 *Draw the schematic set-up of plasma arc machine. Indicate various parts.* **(Fig. 2.22)**

Q.32 *What is the main difference between transferred and non-transferred arc mode in the case of PAM processes ?*

Ans.:

Transferred Arc	Non-Transferred Arc
The electric arc is constituted between an electrode and the workpiece.	The electric arc is constituted between an electrode and the nozzle.
Work piece is made anode, Nozzle is kept electrically neutral.	Workpiece is kept electrically neutral.
Direct arc plasma torch can be applied to electrically conductive work pieces only.	It can be applied to every workpiece regardless of electrical conductivity.

2.7 Long Answered Questions (Part - B)

Q.1 *Explain the process of EDM, its process parameters and applications.* **(Section 2.1.9, Fig. 2.9 and Section 2.19)**

Q.2 *List out the three types of spark generators used in EDM. Describe them.* **(Section 2.1.8)**

Q.3 *With the help of a neat sketch, describe the mechanism of material removal in EDM.* **(Section 2.1.10)**

Q.4 *Explain the different types of control circuits used in EDM process.* (**Fig. 2.4)**

Q.5 *Write about various types of flushing system employed in EDM process.* **(Section 2.1.15)**

Q.6 *What are the basic requirements of tool materials in EDM process ? Name any four tool materials. (**Section 2.1.3**)*

Q.7 *Explain the process of wire cut EDM and list its advantages.* **(Section 2.2.1)**

Q.8 *Explain the principle of working of wire cut EDM process with a sketch.* **(Section 2.2.2)**

Q.9 *What are the advantages and disadvantages of the wire cut EDM process ?* **(Sections 2.2.4 and 2.2.5)**

Q.10 *Explain the following on wire EDM technology.* **(Section 2.2.1)**

a. Dielectric system

b. Deionized water

c. Positioning system

d. Wire drive system

Q.11 *What is EBM ? Sketch its set-up and indicate its parts and explain the principle of operation.* **(Section 2.4.1)**

Q.12 *Describe the EBM process with a simple sketch and write about its process parameters, advantages and applications.* **(Section 2.4)**

Q.13 *Sketch the electron beam gun and explain the functions of each part.* **(Fig. 2.21)**

Q.14 *Explain the principle of LBM with sketch. List out the advantage and limitation of LBM process.* **(Section 2.3)**

Q.15 *List the advantages, disadvantages and applications of LBM process.* **(Sections 2.3.4 , 2.3.5 and 2.3.6)**

Q.16 *Explain the principle of Plasma Arc Machining (PAM).* **(Section 2.5)**

Q.17 *List the advantages, disadvantages and applications of PAM.* **(Sections 2.5.3, 2.5.4 and 2.5.5)**

2.8 Multiple Choice Questions with Answers

ELECTRIC DISCHARGE MACHINING (EDM)

Q.1 In advanced machining processes, what is the full form of EDM ?

a Electro Discharge Machining

b Electro Discharge Manufacturing

c Electrical Dimensioning Machining

d Electrode Dimensions Manufacturing **[Ans. : a]**

Q.2 The evolution of wire EDM took place in which part of history ?

a 1940s

b 1950s

c 1960s

d 1970s **[Ans. : d]**

Q.3 Machining speeds have gone up to how many times after the invention of EDM ?

a Ten

b Twenty

c Thirty

d Fifty **[Ans. : b]**

Q.4 By using EDM, how much percentage of machining costs can be reduced ?

a 10 %

b 20 %

c 30 %

d 50 % **[Ans. : c]**

Q.5 After invention of EDM, surface finish have improved by how much factor ?

a 10 b 15

c 20 d 25 **[Ans. : b]**

Q.6 Cavities with, which of the following factors can be produced using Electro discharge machining ?

a Thin walls b Fine features

c Thin walls & Fine features d None of the mentioned **[Ans. : c]**

Q.7 Which of the following geometries can be machined using EDM ?

a Simple b Complex

c Difficult to cut d All of the mentioned **[Ans. : d]**

Q.8 State whether the following statement is true or false regarding EDM.

"In EDM, process is affected by hardness of material."

a True b False **[Ans. : b]**

Q.9 How much amount of burr is produced in this process ?

a 10 % b 40 %

c 70 % d No burr **[Ans. : d]**

Q.10 Which of the following mechanisms is used for material removal ?

a Electro discharge erosion b Magnetic abrasion

c Electro chemical dissolution d Mechanical erosion **[Ans. : a]**

Q.11 What is the value of order of frequency applied between the two electrodes in EDM ?

a 1 kHz b 3 kHz

c 5 kHz d 7 kHz **[Ans. : c]**

Q.12 What are the magnitude of voltages used in electro discharge machining ?

a 1 to 20 V b 20 to 120 V

c 120 to 220 V d 220 to 320 V **[Ans. : b]**

Q.13 What are the values of gaps between the electrodes in EDM ?

a 0.001 - 0.05 mm b 0.01 - 0.5 mm

c 0.1 - 5 mm d 1 - 15 mm **[Ans. : b]**

Q.14 How is material removed in electro discharge machining ?

a Melt and evaporate b Corrode and break

c Mechanical erosion takes place d None of the mentioned **[Ans. : a]**

Q.15 What is the radius of channel, when electrical breakdown occur ?

a 4 μm b 6 μm

c 8 μm d 10 μm **[Ans. : d]**

Q.16 State whether the following statement is true or false regarding EDM.

"In EDM, negative ions (electrons) collide with positive ions to generate heat."

a True b False **[Ans. : b]**

Q.17 What are the values of temperature that are obtained while machining using EDM ?

a 2000 to 3000 ºC b 4000 to 6000 ºC

c 8000 to 12000 ºC d 15000 to 20000 ºC **[Ans. : c]**

Q.18 What range of heat fluxes are obtained while machining using EDM ?

a 10^{17} W/m^2 b 10^{19} W/m^2

c 10^{24} W/m^2 d 10^{27} W/m^2 **[Ans. : a]**

Q.19 What is the duration of sparks that are produced in Electro discharge machining ?

a 0.001 - 1 μs b 0.1 - 2000 μs

c 0.2 - 100 ms d 100 - 2000 ms **[Ans. : b]**

Q.20 State whether the following statement is true or false about material removal in EDM.

"In EDM, high pressures allow the metal to evaporate."

a True b False **[Ans. : b]**

Q.21 What are the values of pressure of the plasma in EDM ?

a Up to 2 atm b Up to 20 atm

c Up to 200 atm d Up to 2000 atm **[Ans. : c]**

Q.22 At the end of pulse, super-heated metal evaporates ________________.

a explosively b normally

c periodically d occasionally **[Ans. : a]**

Q.23 After the explosion is over, how is the debris carried away ?

a Evaporation b Fresh dielectric

c Old dielectric d All of the mentioned **[Ans. : b]**

Q.24 The layer formed when unexpelled molten metal solidifies is known as _______________.

a reabsorbed layer b recast layer

c unevaporated layer d condensed layer **[Ans. : b]**

Q.25 Amount of material removed from anode and cathode depend on which of the following ?

a Electrons | b Positive ions
c Electrons & Positive ions | d None of the mentioned **[Ans. : c]**

Q.26 What happens when the electron current predominates in the discharge ?

a More anodic removal | b More cathodic removal
c Remains same | d All of the mentioned **[Ans. : a]**

Q.27 Between what values mentioned below, do the discharges and sparks usually vary ?

a 1 and 10,000 | b 500 and 500,000
c 500,000 and 1,000,000 | d None of the mentioned **[Ans. : b]**

Q.28 What is the value of gap maintained between the electrodes when we use servo mechanism ?

a 10 - 100 μm | b 100 - 200 μm
c 200 - 500 μm | d 500 - 1000 μm **[Ans. : c]**

Q.29 Based on the electrode gap, which of the following electric pulses are generated ?

a Open Circuit pulses | b Sparks
c Arcs | d All of the mentioned **[Ans. : d]**

Q.30 State whether the following statement is true or false regarding EDM.

"In Electro discharge machining, electric pulses generated affect the material removal."

a True | b False **[Ans. : a]**

Q.31 Open gap voltages contribute to how much amount of material removal ?

a 20 % | b 50 %
c 70 % | d No contribution **[Ans. : d]**

Q.32 When the electrode gap is too small or electrodes are in contact, how much material is removed ?

a 10 % | b 20 %
c 30 % | d No material removed **[Ans. : d]**

Q.33 Which components mentioned below are affected due to arcs ?

a Work piece | b Tool
c Work piece & Tool | d None of the mentioned **[Ans. : c]**

Q.34 Which of the following pulses contribute to the desired material removal in EDM ?

a Open circuit pulses
b Short circuits
c Arcs
d Sparks **[Ans. : d]**

Q.35 Which of the following are main components of EDM ?

a Dielectric system
b Servomechanism
c Power supply
d All of the mentioned **[Ans. : d]**

Q.36 What is the function of feed-control system in electro discharge machining ?

a Constant gap
b Supply power
c Dielectric fluid supply
d Work piece holding **[Ans. : a]**

Q.37 What is the use of power supply system in electro discharge machining ?

a Constant gap
b Supply power
c Dielectric fluid supply
d Work piece holding **[Ans. : b]**

Q.38 What is the function of dielectric circulation unit in Electro discharge machining ?

a Constant gap
b Supply power
c Dielectric fluid supply
d Work piece holding **[Ans. : c]**

Q.39 Which of the following materials are used as electrodes in EDM ?

a Graphite
b Copper
c Brass
d All of the mentioned **[Ans. : d]**

Q.40 Metals with _________ melting point and _________ electrical conductivity are chosen as tools in EDM.

a low, good
b low, bad
c high, good
d high, bad **[Ans. : c]**

Q.41 Copper has _________ electro discharge machining wear and _________ conductivity.

a Good, better
b Good, worse
c Bad, better
d Bad, worse **[Ans. : a]**

Q.42 Which of the following tungsten carbides are used as electrodes in EDM ?

a Silver tungsten
b Copper tungsten
c All of the mentioned
d None of the mentioned **[Ans. : c]**

Q.43 State whether the following statement is true or false regarding materials used in electro discharge machining.

"In metals, copper graphite has less electrical conductivity than graphite."

a True
b False **[Ans. : b]**

Q.44 Brass metal ensures which type of sparking conditions in electro discharge machining ?

a Stable
b Unstable
c Unsteady
d Insecure **[Ans. : a]**

Q.45 In addition to the feed of tool, electro discharge machining tool can have which type of motion ?

a Oscillatory
b Rotary
c Vibrational
d All of the mentioned **[Ans. : b]**

Q.46 Which of the following parameters determines the size of cavities ?

a Size of electrode
b Radius of orbit
c All of the mentioned
d None of the mentioned **[Ans. : c]**

Q.47 Electrode orbiting ________ the flushing of dielectric fluid in electro discharge machining.

a Improves
b Decreases
c Reduces
d Degrades **[Ans. : a]**

Q.48 Quality of hole produced by orbiting motion is _________ to that obtained by using stationary electrode.

a inferior
b superior
c lower
d all of the mentioned **[Ans. : b]**

Q.49 In EDM, electrode polarity depends up on which of the following components ?

a Work piece
b Electrode material
c All of the mentioned
d None of the mentioned **[Ans. : c]**

Q.50 Which one among the following, is the most important factor in determining the tool wear ?

a Melting point
b Boiling point
c Power supplied
d Feed rate **[Ans. : a]**

Q.51 Electrode wear ratios can be expressed as, which of the following wears ?

a End wear
b Side wear
c Corner wear
d All of the mentioned **[Ans. : d]**

Q.52 The term no wear in EDM occurs when electro-to-work piece wear ratio is __________

a $<1\ \%$
b $<3\ \%$
c $<5\ \%$
d $<10\ \%$ **[Ans. : a]**

Q.53 Which of the following are the other factors that influence the electrode wear ?

a Voltage
b Current
c Electrode material
d All of the mentioned **[Ans. : d]**

Q.54 State whether the following statement is true or false regarding wear in EDM.

"In EDM, electrode wear is less dominant when it comes to micromachining applications."

a True
b False **[Ans. : b]**

Q.55 State whether the following statement is true or false regarding wear in EDM.

"In EDM, corner wear ratio does not depend on type of electrode material."

a True
b False **[Ans. : b]**

Q.56 In electro discharge machining, highest wear ratio is associated with which type of melting point ?

a Low
b Medium
c High
d Very high **[Ans. : a]**

Q.57 Which of the following is not a function of dielectric in EDM ?

a Flush particles
b Cool the section
c Maintain voltage
d Provide insulation **[Ans. : c]**

Q.58 Which of the following are the main requirements of dielectric fluids ?

a Viscosity
b High flash point
c Minimum odour
d All of the mentioned **[Ans. : d]**

Q.59 Which of the following can be used as dielectric fluids in EDM ?

a Kerosene
b Silicon fluids
c Distilled water
d All of the mentioned **[Ans. : d]**

Q.60 In EDM, inadequate flushing will not result in which of the following consequences ?

a Arcing
b Debris removal
c Decrease electrode life
d Increased production time **[Ans. : b]**

Q.61 Which methods below, are used for introducing the dielectric in machining gap ?

a Normal flow
b Reverse flow
c Jet flushing
d All of the mentioned **[Ans. : d]**

Q.62 Few large holes are __________ than many small flushing holes in electro discharge machining.

a worse
b better
c well
d none of the mentioned **[Ans. : a]**

Q.63 State whether the following statement is true or false regarding the dielectric in EDM.

"In EDM, flushing through the tool is more preferred than side flushing."

a True b False **[Ans : a]**

Q.64 In Electro discharge machining, which type of dielectric flow mentioned below is desirable ?

a Unsteady flow b Steady flow

c Unstable flow d None of the mentioned **[Ans. : b]**

Q.65 Metal is removed on which of the components in electro discharge machining ?

a Electrode tool b Work piece

c Electrode tool & Work piece d None of the mentioned **[Ans. : c]**

Q.66 On which of the following components, does the MRR depend ?

a Work piece b Electrode tool

c Electrode tool & Work piece d None of the mentioned **[Ans. : c]**

Q.67 Which of the following factors influence the material removal rate ?

a Pulse condition b Electrode polarity

c Machining medium d All of the mentioned **[Ans. : d]**

Q.68 In electro discharge machining, materials with low melting point have which type of material removal rate ?

a Very low b Low

c Medium d High **[Ans. : d]**

Q.69 In electro discharge machining, materials with low melting point have which type of surface roughness ?

a Rough b Smooth

c Fine d All of the mentioned **[Ans. : a]**

Q.70 What are the values of material removal rates in EDM ?

a 0.001 to 0.1 mm^3/min b 0.1 to 400 mm^3/min

c 400 to 1000 mm^3/min d 1000 to 5000 mm^3/min **[Ans. : b]**

Q.71 What happens to the material removal rate if the sparks are very less in EDM ?

a Decreases b Increases

c Increase and then decrease d All of the mentioned **[Ans. : a]**

Q.72 What is the relation between the melting point and the material removal rate ?

a Directly proportional
b Inversely proportional
c Indirectly proportional
d None of the mentioned

[Ans. : b]

Q.73 What happens to the crater size if we increase the current keeping the pulse time constant ?

a Increase
b Decrease
c Decrease and increase
d None of the mentioned

[Ans. : a]

Q.74 What happens to the crater size if we decrease the pulse time keeping the current constant ?

a Increase
b Decrease
c Increase and decrease
d None of the mentioned

[Ans. : b]

Q.75 On which of the following factors do the craters depend ?

a Physical properties
b Mechanical properties
c Composition of medium
d All of the mentioned

[Ans. : d]

Q.76 The maximum depth of damaged layer is how many times that of average surface roughness ?

a 1.5 times
b 2 times
c 2.5 times
d 3 times

[Ans. : c]

Q.77 What happens to the surface roughness values if the MRR increases in EDM ?

a Increases
b Decreases
c Decrease and increase
d None of the mentioned

[Ans. : a]

Q.78 State whether the following statement is true or false regarding the surface roughness in EDM.

"In EDM, graphite electrodes produce smoother surfaces than metal ones."

a True
b False

[Ans. : b]

Q.79 In electro discharge machining, what happens to the surface finish if the pulse energy is decreased ?

a Reduces
b Decreases
c Improves
d None of the mentioned

[Ans. : c]

Q.80 Using of a mate electrode in electro discharge machining ______________ the surface roughness of material.

a Increases
b Decreases
c Enhances
d None of the mentioned

[Ans. : b]

Q.81 What happens to the surface roughness if oxygen gas is introduced in the gap ?

a increases
b decreases
c decrease and then increase
d all of the mentioned **[Ans. : b]**

Q.82 By how much percent surface roughness is reduced if we use proper dielectric flow ?

a 25 %
b 50 %
c 75 %
d 100 % **[Ans. : b]**

Q.83 What are the tolerance values obtained by machining using EDM ?

a ± 10 mm
b ± 15 mm
c ± 25 mm
d ± 40 mm **[Ans. : c]**

Q.84 How much extra tolerances are achieved when we choose proper variables ?

a ± 5 mm
b ± 10 mm
c ± 15 mm
d ± 20 mm **[Ans. : a]**

Q.85 What are the values of temperatures obtained in electro discharge machining ?

a 1000 to 2000 ºC
b 2000 to 4000 ºC
c 4000 to 8000 ºC
d 8000 to 12000 ºC **[Ans. : d]**

Q.86 What is the value of thickness of recast layer obtained when power of 5 µJ is given ?

a 1 μm
b 3 μm
c 5 μm
d 7 μm **[Ans. : a]**

Q.87 What are the values of thickness of recast layers in electro discharge machining ?

a 0.001 to 0.025 μm
b 0.01 to 0.25 μm
c 1 to 25 μm
d 10 to 250 μm **[Ans. : c]**

Q.88 In electro discharge machining, some annealing of the work piece can be expected ___________ the machined surface.

a on
b just below
c above
d at bottom **[Ans. : b]**

Q.89 The depth of the annealed surface is ___________ to the amount of power used in machining operation.

a directly proportional
b inversely proportional
c exponential
d all of the mentioned **[Ans. : a]**

Q.90 What are the values of thickness of annealed surface obtained while machining using EDM ?

a 1 to 25 μm
b 50 to 200 μm
c 200 to 500 μm
d 500 to 1000 μm **[Ans. : b]**

Q.91 In EDM, choosing electrodes that produce which type of machining reduces the annealing effect?

a Stable
b Unstable
c Uneven
d All of the mentioned **[Ans. : a]**

Q.92 What happens to the fatigue strength of alloys if altered surfaces are produced in electro discharge machining ?

a Increases
b Reduces
c Enhances
d Improves **[Ans. : b]**

Q.93 The altered layers formed during the process of EDM consists of which of the following ?

a Tempered layers
b Heat affected zones
c Intergranular precipitates
d All of the mentioned **[Ans. : d]**

Q.94 During roughing process through electro discharge machining, what is the thickness of layer formed ?

a < 0.075 mm
b < 0.125 mm
c < 0.500 mm
d < 0.750 mm **[Ans. : b]**

Q.95 During finishing process through electro discharge machining, what is the value thickness of layer formed ?

a <0.075 mm
b <0.125 mm
c <0.500 mm
d <0.750 mm **[Ans. : a]**

Q.96 Which of the following processes can be used for restoration of fatigue properties ?

a Low-stress grinding
b Chemical machining
c Reheat treatment
d All of the mentioned **[Ans. : d]**

Q.97 State whether the following statement is true or false regarding the HAZ in EDM.

"In EDM, post treatment to recover fatigue strength is not recommended."

a True
b False **[Ans. : b]**

Q.98 Which of the following shapes can be produced using electro discharge machining ?

a Complex shapes
b Simple shapes
c All of the mentioned
d None of the mentioned **[Ans. : c]**

Q.99 Which of the following materials can be machined using electro discharge machining ?

a Heat resistant alloys
b Super alloys
c Carbides
d All of the mentioned **[Ans. : d]**

Q.100 Which of the following are the applications of electro discharge machining ?

a Holes
b Slots
c Texturing
d All of the mentioned **[Ans. : d]**

Q.101 State whether the following statement is true or false regarding the applications of EDM.

"In advanced machining processes, the incorporation of EDM with CIM increased the length of time for unit operation."

a True
b False **[Ans. : b]**

Q.102 Which type of electrode is used for drilling in electro discharge machining ?

a Flat electrode
b Cuboidal electrode
c Tubular electrode
d Spherical electrode **[Ans. : c]**

Q.103 The dielectric fluid is flushed in thorough which part of the electrode in drilling in EDM?

a Interior hole
b Side gaps
c All of the mentioned
d None of the mentioned **[Ans. : a]**

Q.104 Which type of holes can be produced through drilling using electro discharge machining ?

a Irregular
b Curved
c Tapered
d All of the mentioned **[Ans. : d]**

Q.105 What are the values of general feed rates used for drilling in EDM ?

a 0.1 mm/min
b 0.3 m/min
c 0.5 mm/min
d 0.7 mm/min **[Ans. : a]**

Q.106 What are range of diameter values obtained by drilling using EDM ?

a 0.01 to 0.05 mm
b 0.1 to 0.5 mm
c 1 to 5 mm
d 10 to 15 mm **[Ans. : b]**

Q.107 What are the values of overcuts left behind after drilling of work piece ?

a 0.01 to 0.05 mm
b 0.1 to 0.5 mm
c 1 to 5 mm
d 10 to 15 mm **[Ans. : a]**

Q.108 Electro discharge sawing is an application of EDM which employs __________ as tool material.

a steel band
b disc
c steel band & Disc
d none of the mentioned **[Ans. : c]**

Q.109 When compared to the conventional abrasive sawing, how many times faster is the MRR ?

a Twice
b Thrice
c Four
d Five **[Ans. : a]**

Q.110 How much amount of burr is produce while machined using electro discharge sawing ?

a 10 %
b 20 %
c 50 %
d No Burr **[Ans. : d]**

Q.111 What are the values of finish obtained by machining work piece thorough electro discharge sawing ?

a 0.1 to 4 μm
b 6.3 to 10 μm
c 12.4 to 23 μm
d 25.6 to 40 μm **[Ans. : b]**

Q.112 What are the recast layer thickness values obtained in ED sawing ?

a 0.001 to 0.022 mm
b 0.025 to 0.130 mm
c 0.236 to 0.352 mm
d 0.432 to 0.568 mm **[Ans. : b]**

Q.113 Which of the following electrodes are used for machining spherical surfaces in electro discharge machining ?

a Tubular electrodes
b Flat electrodes
c Cuboidal electrodes
d All of the mentioned **[Ans. : a]**

Q.114 What are the values of dimensional accuracy obtained while machining spherical surfaces ?

a ± 1 μm
b ± 3 μm
c ± 5 μm
d ± 7 μm **[Ans. : a]**

Q.115 What are the surface roughness values obtained while machining spherical surfaces using electro discharge machining ?

a < 0.1 μm
b < 0.3 μm
c < 0.5 μm
d < 0.7 μm **[Ans. : a]**

Q.116 Which motion of tool is used for machining spherical surfaces in electro discharge machining ?

a Oscillatory
b Vibratory
c Rotary
d All of the mentioned **[Ans. : c]**

Q.117 Which type of electrodes are used for milling application in electro discharge machining process ?

a Tubular type electrodes
b Cylindrical type electrodes
c Flat type electrodes
d Spherical type electrodes **[Ans. : b]**

Q.118 Which type of cavities can be machined using milling process by electro discharge machining ?

a Complex cavities
b Simple cavities
c Simple & Complex cavities
d None of the mentioned **[Ans. : c]**

Q.119 The simple electrodes are rotated at which speed for milling of work pieces in electro discharge machining ?

a Very low
b Low
c Medium
d High **[Ans. : d]**

Q.120 What happens to the dielectric flushing while milling tool is rotated at a high speed in EDM ?

a Improved
b Worsen
c Reduced
d All of the mentioned **[Ans. : a]**

Q.121 State whether the following statement is true or false regarding the applications of EDM.

"In EDM, milling process can machine complex shapes with sharp corners."

a True
b False **[Ans. : b]**

Q.122 Which of the following are the steps included in the die sinking process of EDM ?

a CAD of electrode
b Electrode manufacturing
c Programming for die sinking
d All of the mentioned **[Ans. : d]**

Q.123 Wire EDM is a special form of electro discharge machining which contains ___________ electrode.

a continuously moving
b periodically moving
c discontinuously moving
d all of the mentioned **[Ans. : a]**

Q.124 Which path of the components in wire EDM determines the path to be machined ?

a Horizontal worktable movement
b Vertical worktable movement
c Horizontal & Vertical worktable movement
d None of the mentioned **[Ans. : a]**

Q.125 Which of the following materials are machined using wire electro discharge machining ?

a Polycrystalline diamond
b Cubic Boronitride
c Matrix composites
d All of the mentioned

[Ans. : d]

Q.126 How much amount of burr is produce when we use wire electro discharge machining for machining of work pieces ?

a 10 %
b 20 %
c No burr
d Small amount

[Ans. : c]

Q.127 Which of the following industries use wire EDM for different applications ?

a Chemical industry
b Aerospace industry
c Automobile industry
d All of the mentioned

[Ans. : d]

Q.128 While machining insulating ceramic materials using EDM, where is the sheet metal placed ?

a Over material
b Below material
c Under material
d None of the mentioned

[Ans. : a]

Q.129 Sparks occur between which of the following components ?

a Work piece and sheet metal
b Tool electrode and sheet metal
c Work piece and electrode
d None of the mentioned

[Ans. : b]

Q.130 Texturing is applied to the steel sheets at which stages of cold rolling ?

a Initial stages
b Middle stages
c Final stages
d All of the mentioned

[Ans. : a]

Q.131 What is the full form of EDT in EDM processes ?

a Electro Discharge Tinplating
b Electro Discharge Texturing
c Electro Discharge Tapping
d Electro Discharge Turing

[Ans. : b]

Q.132 Which of the following are the process variables for texturing process in EDM ?

a Pulse current
b Electrode polarity
c Dielectric type
d All of the mentioned

[Ans. : d]

Q.133 What are the values of current amplitudes used in EDT ?

a 0.2 to 1 A
b 2 to 10 A
c 20 to 100 A
d 40 to 200 A

[Ans. : b]

Q.134 What are duration values of current amplitude in EDT ?

a 0.1 to 1 μs
b 1 to 10 μs
c 10 to 100 μs
d 100 to 1000 μs **[Ans. : c]**

Q.135 What are the spindle rotation speeds used in EDT ?

a 1 to 4 rpm
b 10 to 40 rpm
c 20 to 60 rpm
d 30 to 90 rpm **[Ans. : b]**

Q.136 What are the values of diameter which are machined using Micro-EDM ?

a 0.001 to 0.01 mm
b 0.01 to 0.1 mm
c 0.1 to 1 mm
d 1 to 10 mm **[Ans. : c]**

Q.137 What happens to the machine capital cost in EDT when there is an increase in tool quantity ?

a Decreases
b Increases
c Remains same
d None of the mentioned **[Ans. : b]**

Q.138 What is the value of depth to diameter ratio in Micro-Electro discharge machining process ?

a 10 : 1
b 5 : 2
c 4 : 3
d 2 : 1 **[Ans. : a]**

Q.139 What are the values of depths that can be machined using Micro-EDM ?

a 1 mm
b 10 mm
c 100 mm
d 1000 mm **[Ans. : c]**

Q.140 What are the machining rates used in Micro-EDM process ?

a 0.1 to 2 mm/min
b 1 to 20 mm/min
c 10 to 200 mm/min
d 100 to 500 mm/min **[Ans. : b]**

Q.141 What are the values of hole diameters obtained using wire electro discharge grinding ?

a 1 μm
b 3 μm
c 5 μm
d 7 μm **[Ans. : c]**

Q.142 What are the feed rates used in WEDG process ?

a 1 to 5 mm/min
b 5 to 10 mm/min
c 10 to 15 mm/min
d 15 to 20 mm/min **[Ans. : b]**

Q.143 Which of the following is a major difficulty in the electro discharge machining process ?

a Proper sparks
b Abnormal discharges
c Optimum feed rates
d No burr **[Ans. : b]**

Q.144 What has been done to the off time when there is a no-load voltage of electric discharge ?

a Increased
b Decreased
c Reduced
d Remains same **[Ans. : a]**

Q.145 In a simple application which of the following parameters are inputs ?

a Pulse duration and current
b Normal and abnormal pulses
c All of the mentioned
d None of the mentioned **[Ans. : a]**

Q.146 In a simple application which of the following parameters are outputs ?

a Pulse duration and current
b Normal and abnormal pulses
c All of the mentioned
d None of the mentioned **[Ans. : a]**

Q.147 Which of the following are correlated with the machining conditions at output stage ?

a Machining depth
b Surface roughness
c Accuracy
d All of the mentioned **[Ans. : d]**

Q.148 How are EDM's levels of integration when compared to conventional machining ?

a Slower rate
b Faster rate
c Same rate
d None of the mentioned **[Ans. : a]**

Q.149 Manufacturing of tool electrode undergoes which of the following processes ?

a Milling
b Turning
c Finishing
d All of the mentioned **[Ans. : d]**

Q.150 High temperatures produced in the working gap results in which of the following potentials ?

a Hazardous smoke
b Toxic vapours
c Aerosols
d All of the mentioned **[Ans. : d]**

Q.151 Hydro carbons present in the dielectric fluid have impact on which of the body parts ?

a Eyes
b Teeth
c Skin
d Nails **[Ans. : c]**

Q.152 What happens to the electro discharge machining process under unfavourable working conditions ?

a Will remain stable
b Explosion may occur
c Machining rate increases
d Nothing happens **[Ans. : b]**

Q.153 Reduction in the electrical energy consumption will have impact on which aspects mentioned below ?

a Environmental

b Economic

c Environmental & Economic

d None of the mentioned

[Ans. : c]

WIRECUT EDM

Q.154 Wire Electric Discharge (ED) machining is based on the same principle as that of _____.

a hydro-dynamic EDM

b die-sink EDM

c polar EDM

d non-conventional EDM

[Ans. : b]

Q.155 The only difference between die-sink EDM and wire cut EDM is the _____.

a way of material removal

b electrode used for the machining

c type of materials machined

d processing time

[Ans. : b]

Q.156 During wire cut EDM, the size of the cavity produced by the wire while machining depends upon _____.

a material of the workpiece

b di-electric fluid used

c wire material

d electric current

[Ans. : d]

Q.157 Sparking gap is the distance between _____.

a the workpiece and the CNC table

b the workpiece and the electrode wire

c the electrode wire and the di-electric fluid

d the workpiece and the spark plug

[Ans. : b]

Q.158 The absolute minimum inner corner radius is _____.

a the wire radius minus the sparking gap width

b the sparking gap width minus the wire radius

c the wire radius plus the sparking gap width

d double of the wire radius

[Ans. : c]

Q.159 The wire ED machines have _____ programmable axes.

a 2

b 2 - 5

c 6

d 3 - 9

[Ans. : b]

Q.160 Which of the following component of the wire cut EDM machine does not get heated ?

a Workpiece

b Electrode wire

c Di-electric fluid

d Coils

[Ans. : b]

Q.161 Which of the following material properties sets restrictions to use wire cut EDM ?

a Material type
b Melting point
c Material hardness
d Electrical conductivity **[Ans. : d]**

Q.162 Wires used in wire cut EDM are usually disposed after one usage.

a True
b False **[Ans. : a]**

Q.163 The electrode wires are usually made form _____.

a graphite
b iron
c nickel
d brass **[Ans. : d]**

Q.164 In wire-cut EDM process, material removal takes place by a series of discrete discharges between _____

a di-electric fluid and the wire electrode
b the wire-electrode and the workpiece
c the workpiece and the CNC-table
d wire electrodes **[Ans. : b]**

Q.165 The di-electric fluid gets ionizes in between _____ gap.

a tool-electrode
b cathode-anode
c workpiece-electrode
d tool-workpiece **[Ans. : a]**

Q.166 The burr or cut particles are flushed away by the______.

a electrode
b motion of the workpiece
c di-electric fluid
d coolant **[Ans. : c]**

Q.167 Wire-cut EDM (WEDM) process is widely used for _____.

a alloy steels
b tool steels
c stainless steels
d carbon steels **[Ans. : b]**

Q.168 For which of the following materials wire-cut EDM is not used ?

a Aluminium
b Zirconium
c Steels
d Titanium **[Ans. : b]**

Q.169 WEDM process can be used for cutting hard extrusion dies.

a True
b False **[Ans. : a]**

Q.170 WEDM process can be used for manufacturing of micro-tools.

a True
b False **[Ans. : a]**

Q.171 How many subsystems are there in wire-cut EDM process ?

a 2
b 3
c 4
d 5 **[Ans. : c]**

Q.172 Di-electric system used in WEDM process is similar to that of the _____ process.

a conventional drilling
b conventional milling
c conventional EDM
d broaching

[Ans. : c]

Q.173 In wire-cut EDM, a moving wire is used to _____.

a remove the burr
b cut complex outlines
c melt the material
d make the way for the di-electric fluid

[Ans. : b]

Q.174 Wire Electric Discharge (ED) machining is based on the same principle as that of _____.

a hydro-dynamic EDM
b die-sink EDM
c polar EDM
d non-conventional EDM

[Ans. : b]

Q.175 The only difference between die-sink EDM and wire cut EDM is the _____.

a way of material removal
b electrode used for the machining
c type of materials machined
d processing time

[Ans. : b]

Q.176 During wire cut EDM, the size of the cavity produced by the wire while machining depends upon _____.

a material of the workpiece
b di-electric fluid used
c wire material
d electric current

[Ans. : d]

Q.177 Sparking gap is the distance between _____

a the workpiece and the CNC table
b the workpiece and the electrode wire
c the electrode wire and the di-electric fluid
d the workpiece and the spark plug

[Ans. : b]

Q.178 The absolute minimum inner corner radius is _____

a the wire radius minus the sparking gap width
b the sparking gap width minus the wire radius
c the wire radius plus the sparking gap width
d double of the wire radius

[Ans. : c]

Q.179 The wire ED machines have _____ programmable axes.

a 2
b 2 - 5
c 6
d 3 - 9

[Ans. : b]

Q.180 Which of the following component of the wire cut EDM machine does not get heated ?

a Workpiece
b Electrode wire
c Di-electric fluid
d Coils

[Ans. : b]

Q.181 Which of the following material properties sets restrictions to use wire cut EDM ?

a Material type
b Melting point
c Material hardness
d Electrical conductivity **[Ans. : d]**

Q.182 Wires used in wire cut EDM are usually disposed after one usage.

a True
b False **[Ans. : a]**

Q.183 The electrode wires are usually made form _____

a graphite
b iron
c nickel
d brass **[Ans. : d]**

Q.184 ______ grades wire are used in automatic re-threading mechanisms.

a Malleable
b Softer
c Harder
d Commercial **[Ans. : c]**

Q.185 For machining of high melting point materials, _____ wires are used.

a gallium
b zinc coated
c aluminium coated
d silver **[Ans. : b]**

Q.186 ______ is/are used as di-electric fluid in die sink EDM process.

a Pure water
b Silicone gel
c Petroleum products
d Epoxy resins **[Ans. : c]**

Q.187 Which of the following is not the application of wire cut EDM process ?

a Machining ejector holes
b Cutting the ejector pins
c Machining cores of various moulds
d Machining of complex shapes made of plastic

[Ans. : d]

Q.188 During mould making by wire cut EDM, it is important to harden ______ to counter the effects of changes in the shape of the workpiece due to heat treatment.

a the insert
b electrode wire
c electrode holding coils
d bolting points in the workpiece **[Ans. : a]**

Q.189 Which of the following machining process is usually preferred for cutting of ejectors which are used in mould making ?

a Milling
b Hobbing
c Wire-cut EDM
d Die sink EDM **[Ans. : c]**

Q.190 How many ways are there for making the fixed cores by wire cut EDM process ?

a 2
b 3
c 4
d 5 **[Ans. : a]**

Q.191 The selection of the manufacturing process depends upon ____________.

a chemical reactivity between the mould material and the di-electric fluid

b mould shape

c application of the mould

d number of parts to be machined **[Ans. : b]**

Q.192 The wire EDM process is used for making moulds with high drafted walls.

a True

b False **[Ans. : a]**

Q.193 For manufacturing of complex shapes, soft electrode wires are used.

a True

b False **[Ans. : a]**

Q.194 Which of the following materials is not machined by wire cut EDM ?

a Inconel

b Graphite

c Tool steel

d Hastaloy **[Ans. : d]**

Q.195 Which of the following does not hold true about wire cut EDM ?

a The electrode wire touches the workpiece while cutting the workpiece material

b It can machine any electrically conductive material irrespective of its hardness

c The di-electric fluid gets ionized in between the tool-electrode gap

d During machining, the electrode wire does not get heated **[Ans. : a]**

Q.196 Which of the following is true about wire cut EDM ?

a Minimal clamping forces are required to hold the workpieces

b It is a conventional process

c It can machine materials like fibres, plastics, wood, etc

d Electrodes used in die sink EDM and wire cut EDM are same **[Ans. : a]**

Q.197 Which of the following is true about wire cut EDM ?

a It leaves no residual burrs

b It cannot machine materials having hardness beyond 20 BHN

c It has poor accuracy as compared to milling

d It uses petroleum products as di-electric fluid **[Ans. : a]**

Q.198 Large scale wire cut EDM machines can handle workpieces weighing upto _____ pounds.

a 100

b 600

c 1000

d 10000 **[Ans. : d]**

Q.199 Wire cut EDM process can cut tapers of _____ degrees.

a 5 - 10 b 8 - 16

c 20 - 30 d 25 - 45 **[Ans. : c]**

Q.200 Wire cut EDM machines work on _____ current.

a direct b alternating

c both direct and alternating d eddy **[Ans. : c]**

Q.201 The heat of each electrical spark generated during machining is around_____ Fahrenheit

a 1,000° to 2,000° b 1,100° to 5,000°

c 10,000° to 12,000° d 15,000° to 21,000° **[Ans. : d]**

Q.202 The de-ionised water is used for flush away the burr as well as to cool the workpiece.

a True b False **[Ans. : a]**

Q.203 In wire cut EDM, machine movement is accomplished with precision lead screws with recirculating ball bearings.

a True b False **[Ans. : a]**

Q.204 Copper is not used for making electrode wires in wire cut EDM because of its _____.

a good conductivity b lower tensile strength

c high melting point d higher purchasing cost **[Ans. : b]**

Q.205 Which of the following materials is not used for electrode wires ?

a Molybdenum b Brass

c Steel d Graphite **[Ans. : c]**

Q.206 Selection of the wire is based on how many factors ?

a 2 b 3

c 4 d 5 **[Ans. : c]**

Q.207 The diameter of the electrode wire is in the range of _____.

a 0.001″ - 0.0035″ b 0.003″ - 0.004″

c 0.004″ - 0.014″ d 0.020″ - 0.032″ **[Ans. : c]**

Q.208 After originating from a supply spool, the wire is passed through _____.

a a chamber filled with special stones b diamond guides

c a furnace d a container filled with anti-oxidant **[Ans. : b]**

Q.209 With the addition of the programmable _____ to wire cut EDM machine, workpieces of different thicknesses can be machined.

a X-axis
b Y-axis
c Z-axis
d chuck **[Ans. : c]**

Q.210 In a wire break situation, the end of the wire is_____ while the supply wire is _____

a clamped, drawn back
b drawn back, clamped
c dipped in the di-electric fluid, clamped
d welded with the other wire, drawn back **[Ans. : a]**

Q.211 The automatic wire threading offers the ability to cut multiple openings in a workpiece without operator intervention.

a True
b False **[Ans. : a]**

Q.212 If there is a wire break during machining, the machine returns to the start point.

a True
b False **[Ans. : a]**

Q.213 After a wire break, the wire tip segment that was clamped is disposed off in a wire tip disposal unit.

a True
b False **[Ans. : a]**

Q.214 In wire cut EDM machine, _______ axes are positioned away from the work area to avoid moisture and contamination.

a X and Y
b X and Z
c U and V
d Y and V **[Ans. : c]**

Q.215 The U and V axes provide movement to the wire to produce taper angles upto _____ degrees.

a 15
b +/– 20
c +/– 30
d 45 **[Ans. : c]**

Q.216 During the wire cut EDM process, the feature of adjustable tapering values is useful for _____.

a circular workpieces
b mould applications
c thick workpieces
d forging dies **[Ans. : b]**

Q.217 The function of independent programming of the U & V axes in wire cut EDM machines is for _______.

a hexagonal workpieces
b fullerene shaped workpieces
c workpieces having a different shape on the top and bottom
d workpieces having intricate shapes **[Ans. : c]**

Q.218 Which of the following is not machined by wire cut EDM ?

a Airfoils
b Extrusion dies
c Square shaped objects
d Perforated sheets **[Ans. : d]**

Q.219 How many sections does the di-electric system includes ?

a 2
b 3
c 4
d 5 **[Ans. : c]**

Q.220 While machining, the dirty water is filtered through a _____.

a paper filter
b notch filters
c comb filters
d fir filters **[Ans. : a]**

Q.221 In a wire cut EDM machine, _____ is used to control the resistivity of the de-electric fluid (water).

a resin beds
b water reservoir
c de-ionisation system
d diamond guides **[Ans. : a]**

Q.222 A water chiller is used to keep _____ thermally stable.

a electrode wire
b electrode coils
c control arms
d dielectric reservoir **[Ans. : c]**

Q.223 During the cutting process water conductivity level changes due to eroded chips.

a True
b False **[Ans. : a]**

Q.224 Submerged machining is extremely useful for applications that generally have______

a poor flushing conditions
b intricate shapes
c tapered sections
d good weldability **[Ans. : a]**

Q.225 Submerged machining is used for ____.

a cutting small taper angles
b tiny workpieces
c laminations
d workpieces with no undercuts **[Ans. : c]**

Q.226 There is a greater risk of breaking a wire if ______.

a temperature of the wire is too high
b larger taper angles are to be cut
c the flush is not set properly
d there is an inadequate flow of di-electric fluid

[Ans. : c]

Q.227 How many of the following processes does not need submerged machining capabilities?

- starting a cut from the edge of a workpiece

- slicing a tube

- slicing a bar stock

- starting a cut from a large diameter start hole.

a 1 | b 2

c 3 | d 4 **[Ans. : d]**

Q.228 When parts with existing openings in them must be cut, conventional flushing produces ______

a air pockets | b unnecessary tapers

c undercuts | d poor flushing **[Ans. : a]**

Q.229 When it is not possible to have the flushing nozzles close to the top or bottom of the workpiece ______ machines may require constant adjustment of the top and bottom flush.

a submerged type | b splash flush

c rigid flush | d stock flush **[Ans. : b]**

Q.230 Which of the following is not the benefit of submerged cutting ?

a improved accuracy | b better surface finish

c Thermal stability | d no wire breakage **[Ans. : d]**

Q.231 Submerged cutting helps cutting the workpieces without hampering the flush.

a True | b False **[Ans. : a]**

Q.232Which of the following is not the effect of less maintenance of the wire cut EDM machines?

a Wire breaks | b Lines in the part

c Lowered time to complete the job | d Rough surfaces **[Ans. : c]**

Q.233 In how many of the following applications, wire cut EDM can be used ?

- Manufacturing of progressive, blanking and trim dies

- Extrusion dies

- Cutting difficult to machine materials like hastaloy, inconel and titanium

- Cutting narrow slots and keyways

- Manufacturing of parts where burrs can't be tolerated.

a 1 | b 3

c 4 | d 5 **[Ans. : d]**

LASER BEAM MACHINING

Q.234 Mechanism of material removal in laser beam machining is due to ______.

a mechanical erosion due to impact of high of energy photons

b electro-chemical etching

c melting and vaporisation due to thermal effect of impingement of high energy laser beam

d fatigue failure **[Ans. : c]**

Q.235 Laser beam is produced due to ______

a spontaneous emission

b stimulated emission followed by spontaneous emission

c spontaneous emission followed by Spontaneous absorption

d spontaneous absorption leading to "population inversion" and followed by stimulated emission

[Ans. : d]

Q.236 Which of the following processes does not use lasers ?

a Cladding
b Alloying
c Nitriding
d Cutting **[Ans. : c]**

Q.237 Lasers are also used for______

a riveting
b nitriding
c rapid prototyping
d facing **[Ans. : c]**

Q.238 Laser stands for light amplification by stimulated emission of radiation.

a True
b False **[Ans. : a]**

Q.239 Laser beams can have power density upto ______

a 1 kW/mm^2
b 10 kW/mm^2
c 1 MW/mm^2
d 10 MW/mm^2 **[Ans. : c]**

Q.240 Laser causes a rapid substantial rise in ______ of the material.

a local temperature
b local pressure
c indentation
d cracks **[Ans. : a]**

Q.241 At ______ temperature an atom is considered to be at ground level.

a absolute zero
b 0 ^oC
c 100 ^oC
d 100 K **[Ans. : a]**

Q.242 The electrons at ground state can be excited to a higher state of energy by ______

a increasing the pressure
b lowering the energy
c absorbing the energy
d oxidising the atom **[Ans. : c]**

Q.243 The geometry and radii of orbital paths of electrons depend on the presence of an electromagnetic field.

a True
b False
[Ans. : a]

Q.244 When coming back to normal state from excited state, electron releases _____

a proton
b anti-proton
c positron
d photon
[Ans. : d]

Q.245 In population inversion, no of electrons in _____ are more as compared to numbers of electrons in _____.

a quasi-stable state, ground state
b meta-stable state, ground state
c meta-stable state, quasi-stable state
d mono-stable state, ground state
[Ans. : b]

Q.246 In laser beam machine, one end of the glass is_____.

a open
b blocked with a 10 % reflective mirror
c blocked with a 75 % reflective mirror
d blocked with a 100 % reflective mirror
[Ans. : d]

Q.247 In laser beam machining, electrons are excited by _____.

a high temperature steam
b flash lamps
c flash torch
d cathode ray tube
[Ans. : b]

Q.248 The photons emitted in the _____ direction form a laser beam.

a vertical
b horizontal
c longitudinal
d lateral
[Ans. : c]

Q.249 How many types of lasers are there ?

a 2
b 3
c 4
d 5
[Ans. : a]

Q.250 How many types of solid state lasers are there ?

a 2
b 3
c 4
d 5
[Ans. : b]

Q.251 Lasers can be operated in _____ modes.

a 2
b 7
c 8
d only one
[Ans. : a]

Q.252 Helium-Neon is a gas laser.

a True
b False
[Ans. : a]

Q.253 Flash tubes used for Nd-YAG laser can be helical or flat.

a True
b False
[Ans. : a]

Q.254 The flash tube is operated in _____ mode.

a pulsed
b continuous
c reversed
d synchronous

[Ans. : a]

Q.255 How many types of flows are possible in gas lasers ?

a 2
b 3
c 4
d 5

[Ans. : b]

Q.256 The power of CO_2 laser is around______

a 15 watt per meter of tube length
b 55 watt per meter of tube length
c 100 watt per meter of tube length
d 1 MW per meter of tube length

[Ans. : c]

Q.257 In a CO_2 laser, a mixture of _____ is circulated through the gas tube.

a CO_2, N_2 and He
b CO_2, N_2 and A_r
c CO_2, H_2 and N_2
d CO_2, I_2 and O_2

[Ans. : a]

Q.258 In CO_2 laser, 'He' gas is used for cooling purpose.

a True
b False

[Ans. : a]

Q.259 CO_2 lasers are folded to achieve _____________

a high power
b high depth of cuts
c high material removal rate
d avoid over heating

[Ans. : a]

Q.260 Nd-YAG laser can be used for drilling holes in the range of _____ diameter.

a 0.25 mm - 1.5 mm
b 1 mm - 1.5 mm
c 1.5 mm - 2 mm
d 2 mm - 2.5 mm

[Ans. : a]

Q.261 For which of the following materials CO_2 laser is not used?

a Plastics
b Metals
c Organic materials
d Ceramics

[Ans. : b]

Q.262 Which of the following does not hold true about laser beam machining?

a High initial cost
b High running cost
c No heat affected zone
d It is not suitable for heat sensitive materials

[Ans. : c]

Q.263 Using lasers, large aspect ratio in drilling can be achieved.

a True
b False

[Ans. : a]

ELECTRON BEAM MACHINING

Q.264 Mechanism of material removal in Electron Beam Machining is due to _____

a mechanical erosion due to impact of high of energy electrons

b chemical etching by the high energy electron

c sputtering due to high energy electrons

d melting and vaporisation due to the thermal effect of impingement of high energy electron

[Ans. : d]

Q.265 Electron beam machining is a/an _____ process

a adiabatic

b thermal

c iso-thermal

d isentropic

[Ans. : b]

Q.266 Electron beam machining is carried out in _____

a high pressure vessel

b thermally insulated area

c vacuum

d in a room at atmospheric pressure

[Ans. : c]

Q.267 During EBM _____ is kept under vacuum.

a electron gun

b whole setup

c the workpiece

d laser generation setup

[Ans. : c]

Q.268 As the electrons strike the work material _____

a heat energy is converted to kinetic energy

b atomic energy is converted to heat energy

c kinetic energy is converted to heat energy

d electrical energy is converted to heat energy

[Ans. : c]

Q.269 The gun in EBM is used in _____ mode.

a wave guide

b biasing

c pulsed

d high intensity

[Ans. : c]

Q.270 Which of the following is not a function of electron beam gun ?

a generation of electrons

b accelerating the electrons

c focusing the beam

d absorbing the electron beam

[Ans. : d]

Q.271 _______ is used to make cathode for electron beam gun.

a Aluminium

b Rubidium

c Molybdenum

d Tantalum

[Ans. : d]

Q.272 Heating to a high temperature leads to thermo-ionic emission.

a True

b False

[Ans. : a]

Q.273 In the electron beam gun, cathode cartridge is highly negatively biased.

a True
b False
[Ans. : a]

Q.274 In electron beam machine, just after the cathode, there is/are _____.

a deflector coils
b a magnetic lens
c bias grid
d port for vacuum gauge
[Ans. : c]

Q.275 Electron is accelerated by _____.

a cathode cartridge
b electromagnetic coils
c aperture
d annular anode
[Ans. : d]

Q.276 ______ determines the mode of an electron beam.

a Applied voltage
b Operating pressure
c Position of magnetic lens
d The nature of biasing
[Ans.: d]

Q.277 After the anode, the electron beam passes through _____.

a cathode cartridge
b deflector coils
c bias grid
d a series of lenses
[Ans. : d]

Q.278 In the electron beam gun, apertures ______.

a allow only convergent electrons to pass
b absorb convergent electrons
c allow divergent electrons to pass
d accelerate the electron beam
[Ans. : a]

Q.279 In the final section of the electron beam gun, electron beam passes through the electromagnetic lens and deflection coil.

a True
b False
[Ans. : a]

Q.280 What is the purpose of a series of slotted rotating discs provided between the electron beam gun and the workpiece ?

a It increases the accuracy of the beam
b It can increase the intensity of the beam (if needed)
c It prevents power losses
d It prevents vapour generated during machining to reach the gun
[Ans. : d]

Q.281 For alignment of the beam, _____ is provided.

a a lens
b a telescope
c magnifier
d microscope
[Ans. : b]

Q.282 The workpiece is mounted on a CNC table.

a True
b False
[Ans. : a]

Q.283 Level of vacuum within the gun is in the order of _____.

a 10^{-4} to 10^{-6} Torr
b 10^{-1} to 10^{-3} Torr
c $10^{-0.65}$ to 10^{-1} Torr
d 1 to 2 Torr

[Ans. : a]

Q.284 In electron beam gun, vacuum is achieved by _____.

a reciprocating pump
b rotary pump only
c combination of rotary pump and diffusion pump
d combination of diffusion pump and vane pump

[Ans. : c]

Q.285 Diffusion pump is an _____.

a oil filter equipment
b oil heater
c oil cooler
d oil collector

[Ans. : b]

Q.286 The oil coming out of diffusion pump is evacuated by a _____.

a screw pump
b gear pump
c rotary pump
d piston pump

[Ans. : d]

Q.287 High velocity gets of oil vapour coming out of diffusion pump entrain ______ present within the gun.

a water droplets
b oil droplets
c air molecules
d hazardous gas molecules

[Ans. : b]

Q.288 Which of the following parameters do not affect the electron beam machining process ?

a Accelerating voltage
b Lens current
c Spot size
d Workpiece material

[Ans. : d]

Q.289 For the electron beam machining process, pulse duration for the electron beam is in range of_____.

a 10 μs to 90 μs
b 50 μs to 15 ms
c 80 μs to 10 ms
d 15 ms to 1 s

[Ans. : b]

Q.290 Beam current is in the range of _____.

a 50 μamp to 0.8 amp
b 100 μamp to 10 amp
c 200 μamp to 1 amp
d 185 μamp to 1.5 amp

[Ans. : c]

Q.291 Increasing the beam current directly increases the _____.

a energy per pulse
b accelerating voltage
c spot size
d lens current

[Ans. : a]

Q.292 In electron beam machining process, the energy density is controlled by spot size.

a True
b False

[Ans. : a]

Q.293 At higher energy densities, material removal rate is high.

a True   b False   **[Ans. : a]**

Q.294 In electron beam machining, the plane of ______ is on the surface of the workpiece.

a focusing   b finishing

c heating   d drilling   **[Ans. : a]**

Q.295 ______ can manoeuvre the electron beam.

a Nozzles   b Magnetic lens

c Electromagnetic coils   d Deflector coils   **[Ans. : d]**

Q.296 Electron beam machining process can machine holes of diameters in the range of ______

a 10 μm to 80 μm   b 50 μm to 100 μm

c 100 μm to 2 mm   d 2 mm to 5 mm   **[Ans. : c]**

Q.297 Which of the following is true about electron beam machining (EBM) ?

a By EBM process, tapered holes can be generated

b Electro-magnetic coils are used to change the direction of the electron beam

c Electron beam gun works under high pressure

d Increasing the current density increases the spot size   **[Ans. : a]**

Q.298 Which of the following holds true for electron beam machining ?

a This process does not generate burr

b Holes having length/diameter ratio as high as 50 can be machined by this process

c In electron beam gun, magnetic lens is used to diverge the beam

d Electron beam is accelerated by electromagnetic coils   **[Ans. : a]**

Q.299 Which of the following materials is not machined by the EBM process ?

a Titanium   b Wood

c Plastic   d Leather   **[Ans. : b]**

Q.300 For EBM process, heat affected zone is about ______

a 10 μm to 80 μm   b 20 μm to 30 μm

c 100 μm to 1 mm   d 2 mm to 5 mm   **[Ans. : b]**

Q.301 Which of the following materials are easy to a machine by EBM process ?

a Aluminium   b Steel

c Plastic   d Wood   **[Ans. : a]**

Q.302 Number of holes drilled per second depends on the holes diameter.

a True   b False   **[Ans. : a]**

Q.303 While machining, there are chances of thermal damage associated with EBM.

a True
b False
[Ans. : a]

PLASMA ARC MACHINING

Q.304 What is the full form of PAM in the advanced machining processes ?

a Plasma Arc Manufacturing
b Plasma Arc Machining
c Plasma Active Manufacturing
d Plasma Active Machining
[Ans. : b]

Q.305 When the Plasma Arc machining process came into the industrial world ?

a 1920s
b 1930s
c 1950s
d 1970s
[Ans.: c]

Q.306 PAM is the only process which works faster in ________ steel than _________ steel.

a stainless, mild
b mild, stainless
c remains same all
d all of the mentioned
[Ans. : a]

Q.307 What is the temperature reached by cathode in order to produce plasma arc ?

a 12000 ºC
b 18000 ºC
c 28000 ºC
d 40000 ºC
[Ans. : c]

Q.308 What is the value of velocity of plasma jet in plasma arc machining ?

a 100 m/sec
b 300 m/sec
c 400 m/sec
d 500 m/sec
[Ans. : d]

Q.309 What is the value of material removal rate in plasma arc machining process ?

a 50 cm^3/min
b 100 cm^3/min
c 150 cm^3/min
d 200 cm^3/min
[Ans. : c]

Q.310 What is the value of specific energy used in Plasma arc machining process ?

a 100 W/(cm^3-min)
b 200 W/(cm^3-min)
c 300 W/(cm^3-min)
d 400 W/(cm^3-min)
[Ans. : a]

Q.311 What is the value of the power used in PAM process ?

a 0.1 - 10 kW
b 2 - 200 kW
c 200 - 400 kW
d 400 - 700 kW
[Ans. : b]

Q.312 What is the value of the voltage used in PAM process ?

a 0.1 - 20 V
b 30 - 250 V
c 300 - 400 V
d 500 - 600 V
[Ans. : b]

Q.313 What is the value of the current used in PAM process ?

a Up to 200 A
b Up to 400 A
c Up to 600 A
d Up to 800 A
[Ans. : c]

Q.314 What is the value of machining speed used in PAM process ?

a 0.1 - 7.5 m/min
b 8.5 - 10.5 m/min
c 15.5 - 19.5 m/min
d 20.5 - 25.5 m/min
[Ans. : a]

Q.315 What is the maximum value of the thickness used in PAM process ?

a 100 mm
b 200 mm
c 300 mm
d 400 mm
[Ans. : b]

Q.316 Which of the following are the different shielded plasmas used in PAM ?

a Gas-shielded plasma
b Water-shielded plasma
c Gas-shielded & Water-shielded plasma
d None of the mentioned
[Ans. : c]

Q.317 Material removal rates depend on which of the following factors ?

a Work piece material
b Type of cutting
c Shielding gases
d All of the mentioned
[Ans. : d]

Q.318 A low power factors indicates ___________ energy required and ___________ removal rates.

a low, low
b low, high
c high, low
d high, high
[Ans. : b]

Q.319 What happens to the machining speed if the thickness of material is increased in PAM ?

a Decreases
b Increases
c Enhanced
d Remains same
[Ans. : a]

Q.320 What is the machining speed required for machining of 12 mm thick plate with 220 kW energy ?

a 1000 mm/min
b 1500 mm/min
c 2000 mm/min
d 2500mm/min
[Ans. : d]

Q.321 How much distortion is produced while machining using PAM ?

a 10 %
b 20 %
c 30 %
d No distortion is produced
[Ans. : d]

Q.322 The cut edge of the material tends to be ___________ than the base metal in PAM.

a smoother
b harder
c same as
d none of the mentioned
[Ans. : b]

Q.323 What is the thickness of the HAZ in PAM ?

a 0.001 to 0.23 mm
b 0.25 to 1.12 mm
c 1.3 to 2.56 mm
d 2.73 to 5.26 mm **[Ans. : b]**

Q.324 How much thickness of cracks may arise beyond HAZ due to rapid cooling ?

a 1.6 mm
b 2.6 mm
c 3.6 mm
d 4.6 mm **[Ans. : a]**

Q.325 What are the values of tolerances obtained by using PAM ?

a ± 0.6 mm
b ± 1.6 mm
c ± 2.6 mm
d ± 3.6 mm **[Ans. : b]**

Q.326 What is the maximum thickness of the walls of tube machined using plasma arc ?

a 10 mm
b 30 mm
c 50 mm
d 70 mm **[Ans. : c]**

Q.327 Which of the following are the advantages of PAM ?

a No chemical
b Less harmful
c Operates cleanly
d All of the mentioned **[Ans. : d]**

Q.328 Which of the following chemicals are used in PAM ?

a Harmful chlorinated fluorocarbons
b Acid cleaning chemicals
c Dissolvable solvent chemicals
d None of the mentioned **[Ans. : d]**

Q.329 How much amount of energy is required for machining using PAM ?

a Low
b Moderate
c High
d Very high **[Ans. : a]**

Q.330 What are the disadvantages of PAM?

a Large power supplies
b Heat produced
c Toxic fumes produced
d All of the mentioned **[Ans. : d]**

Thermal and Electrical Energy Based Processes ends …

Unit - III

Chapter - 3

Chemical and Electro-Chemical Energy Based Processes

Syllabus : Chemical machining and Electro-Chemical machining (CHM and ECM)- Etchants - Maskant - techniques of applying maskants - Process Parameters - Surface finish and MRR-Applications. Principles of ECM – equipments - Surface Roughness and MRR Electrical circuit-Process Parameters ECG and ECH - Applications.

3.1 Chemical Machining

- This process is one of the old material removal processes which employ chemicals for the material removal.
- Nearly all metals and even ceramics can be machined.
- The CHM process is employed where metal removal is difficult or impractical by the conventional machining process.
- In this process, is used for the production are protected from chemical attack by masking.
- This process is used for the production of printed circuit boards (PCB's), engraving, machining of air crafts etc.,

Definition

- CHM is a material removal process used for the production of the required shape and dimensions through selective or overall material removal by controlled chemical attack with acid or alkalis.
- CHM process can be classified into two types

  i) Chemical Milling   ii) Chemical blanking

i) Chemical Milling

- Chemical milling is defined as the process of chemically eroding material to produce "blind" details like pockets, channels, etc.

ii) Chemical Blanking

- This is the process chiefly used for producing details that penetrate material entirely (Holes, Slots etc.,) or to blank complete parts from sheet material by chemically etching the periphery of the desired shape.
- Processing steps for chemical machining

Preparation of work material	Pre cleaning
Masking	Application of chemically resistant material on the places where machining is not required
Etching	To dip or spray exposing the marked material to the reactive environment or etchant

Removal of mask	The maskant applied on the un machined areas are removed and then the work material is cleaned.
Finish	If further process is required, do it or inspect and post process it.

3.1.1 Equipment

- The equipment consists of a tank or container filled with the etchant.
- The work material is either suspended by a hanger or set on a table inside the tank.
- A stirrer is fitted in the tank to ensure uniform etching.
- A heater is also attached inside the tank to accelerate the etching process.
- To ensure uniform material removal, the etchant continuously sprayed onto the part or the part is submerged in the tank of agitated etchant.
- However, too much agitation should be avoided, since it causes areas of cavitation or stagnation which results in ridges, waviness or grooves in the etched surface.

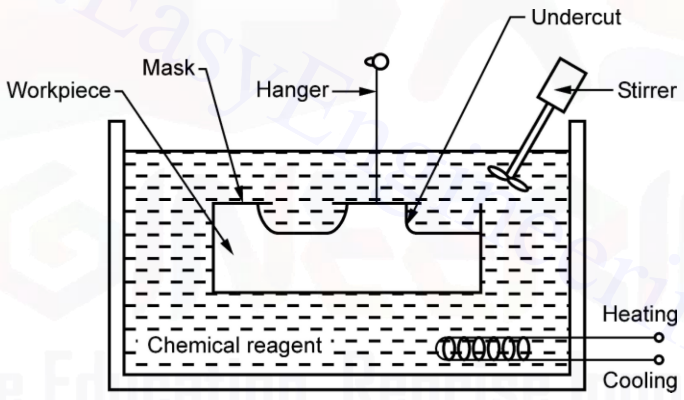


Fig. 3.1

3.1.2 Five Step Process of Chemical Machining

i) Cleaning	ii) Masking	ii) Scribing
iii) Etching	iv) Demasking	

i) Cleaning

- The materials to be machined first cleaned thoroughly to effect uniform adhesion of the maskant and uniform chemical dissolution of the metals.
- Proper cleaning lowers the maskant debonding.

- Depending upon the type of maskant, the required depth of cut and the work piece material the cleaning operation vary from simple solvent to high degree cleaning of operations such as flash etching, vapor degreasing or alkaline etching.
- The porous materials present difficulties for the cleaning process because entrapment of unwanted particles and cleaning solutions.
- When cleaning Aluminium, Magnesium, Steel or titanium alloys the industries adopt the following cleaning process.
  - i) Vapour degreasing
  - ii) Alkaline cleaning
  - iii) Deoxidizing, after cleaning the parts are dried.

ii) Masking

- The chemically resistant mask is applied on the workpiece material by either dip flow coat, airless spray techniques or brushing depends on the part size and configurations.
- Two or more coatings are applied to Aluminium and Magnesium parts while four or more applied to steel, titanium,

iii) Maskants

- Masking material which is called maskant is used to protect workpiece surface from chemical etchant. Polymer or rubber based materials are generally used for masking procedure.
- The selected maskant material should have following properties.
  - Tough enough to withstand handling
  - Well adhering to the workpiece surface
  - Easy scribing
  - Inert to the chemical reagent used
  - Able to withstand the heat used during chemical machining
  - Easy and inexpensive removal after chemical machining etching.
- Multiple maskant coatings are used to provide a higher etchant resistance. Long exposure time is needed when thicker and rougher dip or spray coatings are used.
- Various maskant application methods can be used such as dip, brush, spray, roller, and electro coating as well as adhesive tapes.
- When higher machined part dimensional accuracy is needed, spraying the mask on the workpiece through silk screen would provide a better result.

- Thin maskant coating would cause severe problems such as notwithstanding rough handling or long exposure times to the etchant.
- The application of photo resist masks which are generally used in photochemical machining operation, produce high accuracy, ease of repetition for multiple part etching, and ease of modification.
- Possible maskant materials for different workpiece materials were given in Table.
- Masking materials for vaious chemical machined materials

Workpiece material	Masking material
Aluminium and alloys	Polymer, Butyl rubber, neoprene
Iron based aloys	Polymer, polyvinyl chloride, polyetilien butyl rubber
Nickel	Neoprene
Magnesium	Polymer
Copper and alloys	Polymer
Titanium	Polymer
Silicon	Polymer

iv) Scribing

- After the application of maskant on the workpiece material the required areas are to be machined are scribed by using knife.
- Patterns and templates are used for obtaining the required shape of the area to be machined chemically.
- Epoxy-impregnated fibre glass, Aluminium, steel are commonly used templates.
- The blank part is scribed with the desired pattern as determined by template.
- After the part is scribed, the maskant in the scribed area is peeled off, leaving the areas for etching.
- Time of immersion of the workpiece in the etchant is determine the depth of cut.

v) Etching

- The etching of the work material done by adopting immersion or spraying technique.
- The etching is done until required depth of cut is obtained.
- Step etching is done by repeated cycles of masking and peeling off.
- Also the pans are rotated during the cycle to ensure uniform etching.

3.1.3 Etchant

- The purpose of etchant is to dissolve the workpiece material by turning it into a metallic salt, which goes into the solution.
- Etchants are the most influential factor in the chemical machining of any material. Various etchant are available due to workpiece material. The best possible etchant should have properties as follows
  - High etch rate
  - Good surface finish
  - Minimum undercut
  - Compatibility with commonly used Maskants
  - High dissolved-material capacity
  - Economic regeneration
  - Easy control of process.
  - Personal safety maintenance

Etchant Selection

Required Surface finish	Some combination of material and etchant result in the formation of surface oxide, which degrade the finish
Removal rate	Faster rates lower the cost, but attack the resist bond, result in poor finish or producing high heat
Material type	Etchant must attack the material without causing embrittlement or corrosion cracking
Etch depth	Some etchants produce surface finishes that worsen with increasing depth
Type of resist	Etchant must destroy resist during the process time.
Cost	Cost of the etchant, maintenance and disposal must be considered

3.1.4 Demasking

- Final step is to remove masking material from etched part. The inspections of the dimensions and
- Surface quality are completed before packaging the finished part.

Method of Masking

Masking can be achieved by any of the following process

- Cut and peel
- Photographic resist
- Screen resist

Cut and Peel

- Apply maskant over entire part by dipping, spraying or painting.
- Maintain the maskant thickness as 0.025 mm to 0.125mm
- After the machining process, maskant can be removed by hand or using knife.
- This type of technique mostly employed in where the accuracy is not important.

Photographic Resist

- In this method photographic technique is used for masking.
- The maskant material contain photo sensitive materials.
- This process is normally applied where small parts are produced in high quantities and close tolerances are required.

Screen Resist

- The maskant is applied by means of silk screening method.
- Maskant is painted on the work parts surface through a silk or steel mesh.
- This method is usually adapted where the accuracy is moderate.
- Tolerance ± 0.075 mm can be achieved with this masking method.

3.1.5 Advantages

The application of chemical machining provides several advantages as follows

- Easy weight reduction
- No effect of workpiece materials properties such as hardness
- Simultaneous material removal operation
- No burr formation
- No stress introduction to the workpiece
- Low capital cost of equipment
- Easy and quick design changes
- Requirement of less skilled worker
- Low tooling costs

- The good surface quality
- Using decorative part production
- Low scrap rates (3 %).

3.1.6 Disadvantages

- Difficult to get sharp corner
- Difficult to chemically machine thick material (limit is depended on workpiece material, but the thickness should be around maximum 10 mm)
- Scribing accuracy is very limited, causes less dimensional accuracy
- Etchants are very dangerous for workers
- Etchant disposals are very expensive

3.1.7 Environmental Issues in Chemical Machining

Environmental issues in chemical machining operations may be the most important factor affects the machining process should be used or not. Most of the chemicals such as cleaning solutions, etchants, strippers etc. are very hazardous liquids. Therefore handling and disposal of them are very costly. Industrial trend of using these chemicals are to select more environmentally accepted ones for chemical machining process. Moreover, regeneration of waste etchant and etched metal recovery from waste etchants have been studied and there could be a suitable regeneration/recovery systems for some etchants like $FeCl_3$, $CuCl_2$ and alkaline etchants.

3.2 Electrochemical Machining

- Electrochemical Machining (ECM) is a non-traditional machining (NTM) process belonging to Electrochemical category.
- It is a method of removing metal by an electrochemical process. It is best suited for the metals and alloys which are difficult to machine by conventional process.
- It can able to cut intricate shapes even in hard metals like titanium aluminides, Inconel, waspalloy etc., both external and internal surfaces can be machined.
- ECM is a anodic dissolution of atomic level of work piece that is electrically conductive by a shaped tool due to flow of high current through electrolyte.

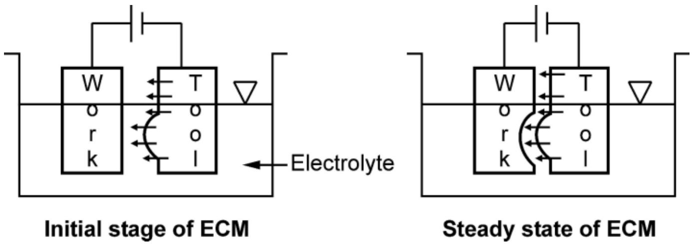


Fig. 3.2 Schematic principle of Electro Chemical Machining (ECM)

3.2.1 Principle

This process based on Faraday's Law of electrolysis

1. First law states that the amount of any material dissolve or deposited is proportional to the quantity of electricity passed.
2. Second law states that, the amount of change produced in the materials is proportional to its electrochemical equivalent of the materials.

- ECM is the reverse electroplating method.

ECM	Electroplating
Material removed from the work piece	Metal deposited on the work piece
Workpiece connected to positive terminal and the tool is connected to negative terminal.	Work piece is connected to negative terminal and the tool is connected to positive terminal.
When the current passed the work piece loses metal and the dissolved metal is carried out by circulating an electrolyte between work and tool	Tool loses material and the metal deposited on the work piece.

3.2.2 Construction and the Working of ECM Process

- Electrochemical machining (ECM) is a machining process in which electrochemical process is used to remove materials from the workpiece. In the process, workpiece is taken as anode and tool is taken as cathode.
- The two electrodes workpiece and tool is immersed in an electrolyte (such as NaCl).
- When the voltage is applied across the two electrodes, the material removal from the workpiece starts.
- The workpiece and tool is placed very close to each other without touching.

- In ECM the material removal takes place at atomic level so it produces a mirror finish surface.
- This process is used to machine only conductive materials.
- ECM working is opposite to the electrochemical or galvanic coating or deposition process.
- During electrochemical machining process, the reactions take place at the electrodes i.e. at the anode (workpiece) and cathode (tool) and within the electrolyte.
- Let's take an example of machining low carbon steel which is mainly composed of ferrous alloys (Fe).
- We generally use neutral salt solution of sodium chloride (NaCl) as the electrolyte to machine ferrous alloys.
- The ionic dissociation of NaCl and water takes place in the electrolyte as shown below.

$$NaCl \rightarrow Na^{+} + Cl^{-}$$

$$H_2O \rightarrow H^{+} + OH^{-}$$

- As the potential difference is applied across the electrode, the movement of ions starts in between the tool and w/p. The positive ions moves towards the tool (cathode) and negative ions move towards the workpiece.
- At cathode the hydrogen ions takes electrons and gets converted into hydrogen gas.

$$2H^{+} + 2e^{-} \rightarrow H_2\uparrow$$

- In the same way the iron atoms comes out from the anode (w/p) as Fe++ ions.

$$Fe \rightarrow Fe^{++} + 2e^{-}$$

- Within the electrolyte, the sodium ions combines with Hydroxyl ions and form sodium hydroxide and ferrous ion combine with Chloride ions and forms ferrous chloride. Also iron ions combine with hydroxyl ions and forms Iron hydroxide.

$$Na^{+} + OH^{-} \rightarrow NaOH$$

$$Fe^{2+} + 2Cl^{-} \rightarrow FeCl_2\downarrow$$

- In the electrolyte the $FeCl_2$ and $Fe(OH)_2$ produced and gets precipitated in the form of sludge and settle down. In this way material is removed from the workpiece as sludge.
- The various reactions taking place in the Electrochemical machining process are in the figure given below

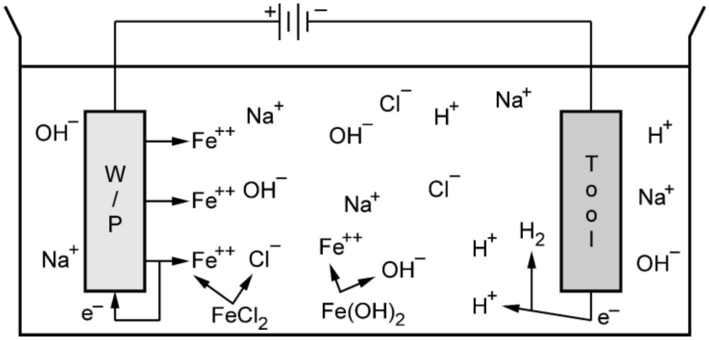


Fig. 3.3 Chemical reaction of ECM

3.2.3 Main Equipment of ECM

- The ECM system has the following modules
  - Power supply
  - Electrolyte filtration and delivery system
  - Tool feed system
  - Working tank

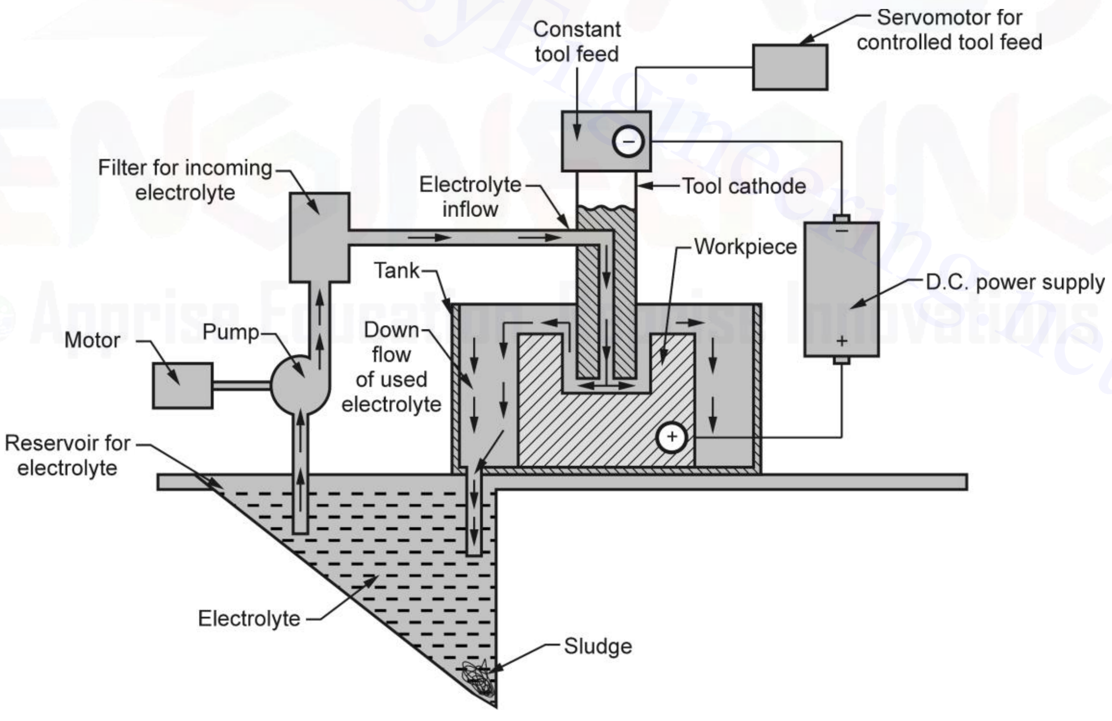


Fig. 3.4 Schematic diagram of ECM

3.2.4 Working Process of Electrochemical Machining

- First the workpiece is assembled in the fixture and tool is brought close to the workpiece. The tool and workpiece is immersed in a suitable electrolyte.
- After that, potential difference is applied across the w/p (anode) and tool (cathode). The removal of material starts. The material is removed as in the same manner as we have discussed above in the working principle.
- Tool feed system advances the tool towards the w/p and always keeps a required gap in between them. The material from the w/p is comes out as positive ions and combine with the ions present in the electrolyte and precipitates as sludge. Hydrogen gas is liberated at cathode during the machining process.
- Since the dissociation of the material from the w/p takes place at atomic level, so it gives excellent surface finish.
- The sludge from the tank is taken out and separated from the electrolyte. The electrolyte after filtration again transported to the tank for the ECM process.

3.2.5 Parameters in ECM

1) Metal Removal Rate (MRR) - It depends on the following factors :

(a) Current density

(b) Conductance of electrolyte

(c) Voltage applied

(d) Shape of electrodes

(e) Gap between the tool and workpiece.

2) Electrolyte used - Following are the types of electrolyte used in the ECM process :

(a) Sodium chloride

(b) Sodium chromate

(c) Sodium hydroxide

(d) Potassium nitrate

(e) Sodium sulphate

(f) Potassium chloride

(g) Sodium fluoride

The electrolyte is used in the process for following purposes :

(a) It carries current between the tool and workpiece.

(b) It flushes away the sludge and other contaminants from the machining area.

(c) It minimizes heat generated in the cutting zone due to current and chemical reaction.

3) Tool for ECM -

- The shape of the tool is reproduced on the workpiece, hence the tool face should be well polished to obtain good surface finish on the workpiece. The tool used in the process should have following properties :

(a) It should be good conductor of electricity.

(b) It should be easily machinable.

(c) It should have high chemical resistance.

(d) It should be easily available and cheap.

Most commonly used materials for ECM process are :

(a) Copper

(b) Brass

(c) Stainless steel

(d) Titanium

3.2.6 Applications

- The ECM process is used for die sinking operation, profiling and contouring, drilling, grinding, trepanning and micro machining.
- It is used for machining steam turbine blades within closed limits.

3.2.7 Advantages

- Negligible tool wear.
- Complex and concave curvature parts can be produced easily by the use of convex and concave tools.
- No forces and residual stress are produced, because there is no direct contact between tool and workpiece.
- Excellent surface finish is produced.
- Less heat is generated.

3.2.8 Disadvantages

- The risk of corrosion for tool, w/p and equipment increases in the case of saline and acidic electrolyte.

- Electrochemical machining is capable of machining electrically conductive materials only.
- High power consumption.
- High initial investment cost.

3.2.9 Process Capabilities

S. No.	Parameters	Values
1.	Power supply	
	Type	Direct Current
	Voltage	2 to 35 V
	Current	50 to 40,000 A
	Current Density	0.1 A/mm^2 to 5 A/mm^2
2.	Electrolyte	
	Material	NaCl and $NaNO_3$
	Temperature	20 °C to 50 °C
	Flow rate	20 lpm/100 A current
	Pressure	0.5 to 20 bar
	Dilution	100 g/l to 500 g/l
3.	Working gap	0.1 mm to 2 mm
4.	Overcut	0.2 mm to 3 mm
5.	Feed rate	0.5 mm/min to 15 mm/min
6.	Electrode material	Copper, brass and bronze
7.	Surface roughness (Ra)	0.2 to 1.5 μm

3.3 Electro Chemical Grinding (ECG)

- ECG is the material removal process in which the material is removed by the combination of Electro-chemical deposition as in ECM process and abrasion due to grinding.

Process :

- ECG is a combination of ECM and the grinding process. The metal is removed by both anodic dissolution as in ECM and abrasion by the grinding wheel.
- Conventional grinding of carbides, high strength temperature resistant alloys and hard to machine alloys become very costly because of employing the high cost abrasives and diamond wheels.
- The possibility of cracking in the grinding wheels due to the abrasion of hard materials is eliminated in the ECG process.
- Hard and difficult to machine, fragile, and electrically conductive materials can be easily machined by ECG process. In this process, 10 % of the work material is removed by abrasive cutting and 90% by electrolytic action.

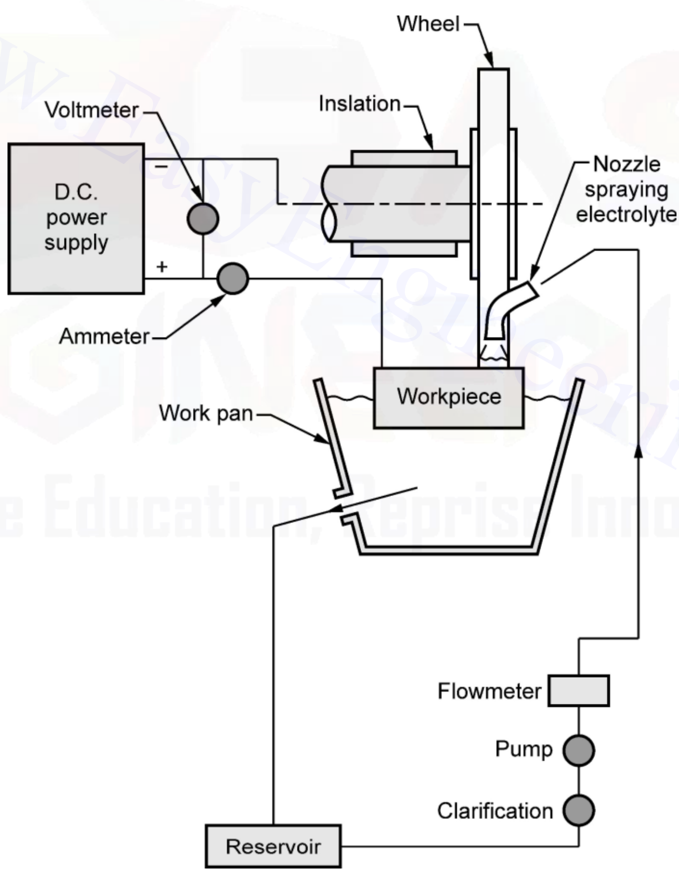


Fig. 3.5 ECG process

3.3.1 Equipment

- The equipment consists of a conductive grinding wheel rotated by an insulated spindle, an electrolyte spraying and circulating unit and a work table for achieving desired shape and size of machining.
- Also a DC power supply unit is employed for the supply of electrical energy. At the outset, the ECG equipment is similar to a conventional grinder.
- The grinding wheels used in ECG process are conductive ones. It consists of abrasive particles in an electrically conductive bonding agent.
- **Copper, Brass, Nickel are the most commonly used materials for metal-bond wheels.** Soft, copper-impregnated resins are used when wheels are fabricated for form-Grinding applications.
- The most common abrasive used is Aluminium oxide. In special applications, a solid metal disk with a layer of diamond particles, in a nickel matrix is used.
- The abrasive particles of the grinding wheel are non-conductor of electricity. The abrasive grits on the grinding wheel are made to protect from 0.0125 mm to 0.0375 mm from the surface of the grinding wheel.
- The grinding wheels are dressed in the conventional way using a diamond dresser. Several techniques are employed to maintain the proper gap between the wheel and workpiece during machining.
- The grinding wheel and the spindle are insulated from the rest of the machine. The short circuit between the wheel and the work piece is prevented due to point contact made by the fine diamond points.
- Two methods are currently employed to carry power through the spindle, the brushes and mercury couplings.
- Most of the ECG machines use heavy metal brushes to provide sliding electrical connection. But the use of brushes is limited because of its inability to carry high current. The mercury couplings are used to carry high current and ensure for higher material removal.
- The electrolyte system consists of pump, filter, Relief valve etc., the electrolyte is pumped in the gap between the work and the grinding wheel.
- The used electrolyte contacting the removed material and sludges are collected in the reservoir from which it passes through the filter and is pumped to the machining area through flow control and relief valve.

- The feeding mechanism is attached to the machine table provides the feed to the workpiece.

3.3.2 Working Principle

- The workpiece is made as anode which is connected to the positive terminal of the DC power supply and the grinding wheel tool is made as the cathode.
- A small gap of approximately 0.025m is maintained between the work surface and grinding wheel.
- A suitable electrolyte is fed into the gap through nozzle. When a low voltage of 4 to 15 volts and current of 100 amps is applied between the tool and the workpiece.
- A high density current (77 to 620 amp/cm^2) passes through them.
- The whole system forms an electrolytic cell and hence machining occurs by,

    a) Anodic dissolution of the workpiece.

    b) Abrasive action of the grits of the wheel.

When voltage is applied, the work material gets dissolved in the electrolyte and as the wheel rotates, the abrasive particle remove the material by abrasive action.

Material Removal Rate

The material removal rate in electrochemical Grinding can be calculated from the equation,

$$MRR = \frac{MI}{\rho F}$$

M is equivalent weight in grams

I is the current in ampere

ρ is density g/mm^3

F faradays constant in coulomb

3.3.3 Advantages

1. No thermal damage to the work piece.
2. About 80% faster material removal rate than conventional grinding
3. Long lasting wheels because 10% grinding action by grits.
4. Wheel wear is negligible.
5. No distortion of the workpiece.
6. No micro-crack and no structural changes occur in the workpiece.
7. Cutting force is very small compared to conventional grinding.

8. Higher accuracy is achieved. (about 0.01mm)
9. Single pass grinding.
10. More economical for grinding harder material than conventional grinding.

3.3.4 Disadvantages

1. High capital costs, Because of the special tool and insulation arrangements.
2. Power consumption is quite high.
3. Electrolyte is corrosive.
4. The electrolyte and the bonding material should have high electrical conductivity.
5. High Preventive maintenance costs.

3.3.5 Limitations

1. The work material must be conductive.
2. Not suitable for machining soft materials.
3. Require dressing tools for preparing the wheels.

3.3.6 Applications

1. Precision grinding of hard metals economically.
2. Grinding carbide cutting tool inserts.
3. To Re-profile motor gears, gear teeth and re-establish new teeth contour.
4. Burr-free sharpening of hypodermic needles, grinding of super alloy turbine blades and form grinding of fragile honeycomb metals.
5. To grind end mill cutters more precisely.
6. Thin walled components of hard steels can be easily and accurately ground by this process.

3.4 Electro Chemical Honing (ECH)

- Electro Chemical Honing process comes under the process of Electro Chemical Machining process. It is the usage of combined power of electricity and chemical energy for the material removal from the work piece is known as Electro Chemical Machining process.
- Electro Chemical Honing process is mostly employed for better surface finish, accuracy and economic aspects too.

- Honing is an abrasive machining process that produces a precision surface on a metal workpiece by scrubbing an abrasive stone against it along a controlled path.
- Honing is primarily used to improve the geometric form of a surface, but may also improve the surface texture.
- A special tool, called a honing stone or a hone, is used to achieve a precision surface.
- The hone is composed of abrasive grains that are bound together with an adhesive.
- Generally, honing grains are irregularly shaped and about 10 to 50 micrometers in diameter (300 to 1,500 mesh grit).
- Smaller grain sizes produce a smoother surface on the workpiece.
- Hone tool has a combined motion of rotation and translation
- A honing stone is similar to a grinding wheel in many ways, but honing stones are usually more easily crumbled so that they conform to the shape of the workpiece as they wear in.
- To counteract their friability, honing stones may be treated with wax or sulfur to improve life; wax is usually preferred for environmental reasons.
- Any abrasive material may be used to create a honing stone, but the most commonly used are corundum, silicon carbide, cubic boron nitride, or diamond.

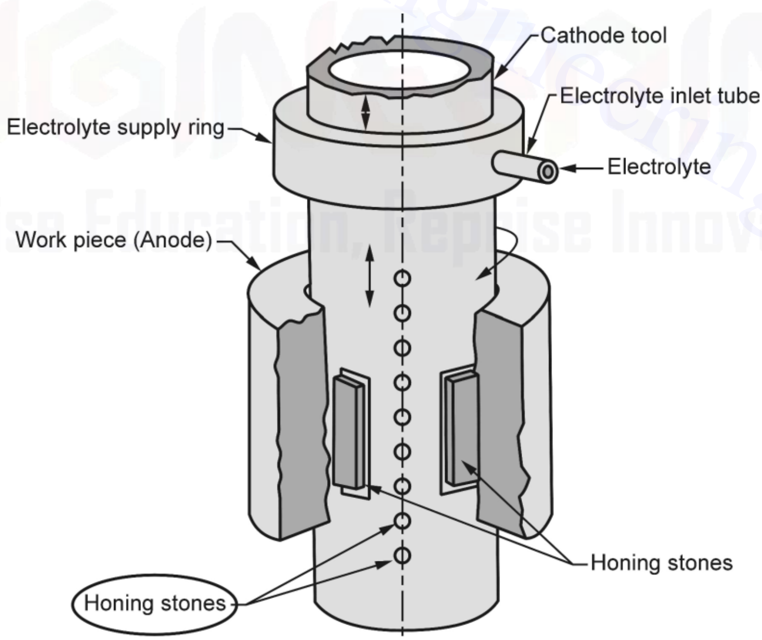


Fig. 3.6 Structure of hone tool

- In an electrochemical honing process, in order to obtain better accuracy, the size of the tolerance on the diameter can be provided at 0.01 mm and roundness can be maintained at lesser than 0.05 mm.
- It provides the surface roughness in the range of 0.1 microns to 0.5 microns. To attain a specified roughness on the work surface, the abrasive honing stones are required to keep on the work for a few seconds after the power is cut off.
- The surface finish of the electrochemical honing process obtained is mostly based up on the following terms.
  1. Size of the abrasive grains.
  2. Speed of the rotation and reciprocation.
  3. Duration of the run out period.

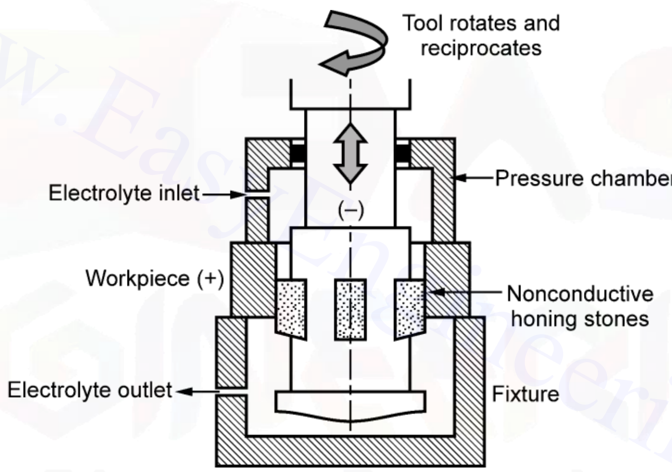


Fig. 3.7

3.4.1 Process Characteristics

- Abrasive stones are used to maintain the gap size of 0.075 to 0.250 mm.
- Surface finish ranges from: 0.2 to 0.8 μm.
- Electrolyte temperature is nearly maintained at 38-40 °C.
- Pressure of 1000 kPa.
- Flow Rate : 95 L/min.
- DC current is used.
- Voltage gap of 6 to 30 V is kept accordingly.
- Current density of 465 A/cm^2 .
- Cross-hatched cut surface is obtained after machining which is most desired after any load bearing surface.

- Tolerance can be achieved is as low as ±0.003 mm.
- Material removal rate is 3 to 5 times faster than conventional honing and 4 times faster than that of internal cylindrical grinding.

3.4.2 Advantages of Electorchemical Honing Process

1. Electrochemical honing process enhances the material removal rate specifically for harder materials.
2. There is no presence of burrs on the finished surfaces.
3. Electrochemical honing process requires minimum amount of work pressure on the tool and the work piece.
4. Electrochemical honing process reduces the noise level and distortion while honing thin walled tubes.
5. Electrochemical honing process increases the accuracy without damaging the materials due to the provision of cooling medium.

3.4.3 Disadvantages

- Machinery cost is high
- Machining cost per piece increases as it is an addition process.

3.4.4 Applications

- Due to rotating and reciprocating honing motion, the process reduces the errors in roundness through the rotary motion.
- Taper and waviness errors can also be reduced

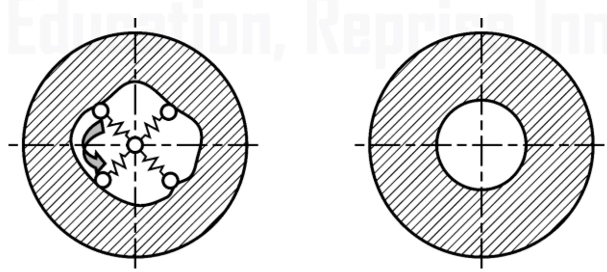


Fig. 3.8 Removing roundness error

- Typical applications are the finishing of cylinders for internal combustion engines, air bearing spindles and gears.

3.5 Two Marks Questions with Answers (Part - A)

Q.1 *What are the advantages of chemical machining ?* **(Section 3.1.5)**

Q.2 *What are the factors influencing the selection of maskants in chemical machining process ?* **(Section 3.1.2 (iii))**

Q.3 *What are maskants in chemical machining process ?* **(Section 3.1.2 (iii)Table)**

Q.4 *Write the principle of Electro Chemical Machining (ECM) ?* **(Section 3.2.1)**

Q.5 *Name any two electrolytes used in ECM.* **(Section 3.2.5 (2))**

Q.6 *What are the materials used for tools in ECM ?* **(Section 3.2.5 (3))**

Q.7 *What are the process parameters of ECM ?* **(Section 3.2.5 (1))**

Q.8 *What is the function of electrolyte in ECM ?* **(Section 3.2.5 (2))**

Q.9 *Mention the applications of ECM.* **(Section 3.2.6)**

Q.10 *Mention a few advantages of ECM process.* **(Section 3.2.7)**

Q.11 *What is the basic difference between electro plating and ECM ?* **(Section 3.2.1 (Table))**

Q.12 *State the working principle of ECG.* **(Section 3.3.2)**

Q.13 *State the advantages of ECG.* **(Section 3.3.3)**

Q.14 *Give the applications of Electro Chemical Honing (ECH) process.* **(Section 3.4.4)**

Q.15 *Write any two process characteristics of ECH ?* **(Section 3.4.1)**

3.5 Long Answered Questions (Part - B)

Q.1 *Describe the working principle and elements of chemical machining.* **(Section 3.1.1)**

Q.2 *Briefly explain the following with respect to chemical machining.* **(Section 3.1.2)**

a. Characteristics of cut and peel maskants

b. Selection of maskants

c. Advantages of photoresist maskant

d. Limitations of chemical machining.

Q.3 *List the advantages of chemical machining process.* (**Section 3.1.5)**

Q.4 *Why maskants are required in chemical machining process ? Explain.* **(Section 3.1.2 (iii))**

Q.5 *During the machining of Iron (Fe) using aqueous solution of Nacl, what are the possible reactions at electrodes ?* (**Section 3.2.2)**

Q.6 *Explain the ECM process. Explain how a replica of the tool is obtained.* (**Section 3.2)**

Q.7 *Explain in detail ECM process with sketch and also mention the advantages and application.* (**Sections 3.2.4 , 3.2.6 and 3.2.7)**

Q.8 *Explain the process of electro chemical machining with a neat sketch and discuss about influences of process parameters in machining output.* (**Section 3.2.5)**

Q.9 *Describe the principle of ECG and ECH. Discuss about the process parameters that influences the ECM.* (**Sections 3.3 and 3.4)**

Q.10 *Explain the working principle of Electro Chemical Grinding (ECG) and discuss the process capabilities and application.* (**Section 3.3)**

Q.11 *Explain the principle of ECG with sketch.* (**Sections 3.3.1 and 3.3.2)**

Q.12 *Describe the Electro Chemical Honing (ECH) process with a neat sketch.* (**Section 3.4)**

3.7 Multiple Choice Questions with Answers

Chemical Machining

Q.1 In advanced machining processes, what is the full form of CHM ?

a Chemical machining
b Chemical manufacturing
c Chemical machining
d None of the mentioned **[Ans. : a]**

Q.2 Of the following, which mechanism is used for the removal of material using chemical machining process ?

a Material vaporization
b Chemical dissolution
c Mechanical erosion
d Mechanical abrasion **[Ans. : b]**

Q.3 Which of the following solutions cannot be used as chemical reactive solution in CHM ?

a Acidic solution
b Alkaline solution
c Neutral solution
d None of the mentioned **[Ans. : c]**

Q.4 By using chemical machining, which of the following can be produced ?

a Pockets
b Contours
c Slots
d All of the mentioned **[Ans. : d]**

Q.5 Pre cleaning is done on the work piece surface in order to achieve, which of the following factors ?

a To provide good adhesion
b To provide clean surface
c To assure the absence of contaminants
d All of the mentioned **[Ans. : d]**

Q.6 Special coatings applied on work piece materials in order to protect them from chemical reaction are known as _________.

a maskants
b protective coverings
c protective varnishing
d none of the mentioned **[Ans. : a]**

Q.7 Type of mask depends on which of the factor/s, given below ?

a Size of work piece
b Number of parts
c Desired resolution
d All of the mentioned **[Ans. : d]**

Q.8 During chemical machining, depth of etch is controlled by which factor of immersion ?

a Time
b Mask method
c Mask area
d None of the mentioned **[Ans. : a]**

Q.9 What is the range of reagent temperatures used for chemical dissolution in CHM ?

a 12 °C to 35 °C
b 37 °C to 85 °C
c 90 °C to 101 °C
d 121°C to 142 °C **[Ans. : b]**

Q.10 In chemical machining, excessive flow of chemical reagent results in which of the following defects ?

a Channellings
b Grooves
c Ridges
d All of the mentioned **[Ans. : d]**

Q.11 State whether the following statement about chemical machining is true or false.

"At higher temperatures, faster etching rates occur in chemical machining."

a True
b False **[Ans. : a]**

Q.12 Of the following, which ratio defines the etch factor ?

a Etching depth to undercut
b Undercut to etching depth
c Undercut to mask area
d Mask area to undercut **[Ans. : b]**

Q.13 CHM cannot eliminate which of the following defects ?

a Irregularities and dents
b Surface scratches
c Waviness
d All of the mentioned **[Ans. : d]**

Q.14 Which of the following are the tools required for chemical machining ?

a Maskants
b Etchants
c Scribing plates
d All of the mentioned **[Ans. : d]**

Q.15 State which of the following statement is true or false regarding chemical machining.

"Maskants are generally used in CHM, to protect the work piece from the etching chemical agent."

a True
b False **[Ans. : a]**

Q.16 Which of the following are the materials used for making maskants ?

a Synthetic materials
b Rubber materials
c Polymeric materials
d All of the mentioned **[Ans. : d]**

Q.17 What are the properties that a maskant used in chemical machining should possess ?

a Be tough and adhere well | b Scribe easily
c Be inert to chemical reagent | d All of the mentioned **[Ans. : d]**

Q.18 Which of the following can be used to apply the maskants on work piece in chemical machining ?

a Dipping or spraying | b Rolling or electro coating
c Adhesive tapes | d All of the mentioned **[Ans. : d]**

Q.19 State whether the following statement is true or false regarding maskants.

"After etching, maskants should be removed easily and inexpensively."

a True | b False **[Ans. : a]**

Q.20 In maskant application, photo-resist masks ensure which of the following advantages ?

a High accuracy | b Ease of repetition
c Ease of modification | d All of the mentioned **[Ans. : d]**

Q.21 Which of the tolerance values are obtained, when we use cut and peel mask method for maskant ?

a ± 0.013 mm | b ± 0.045 mm
c ± 0.077 mm | d ± 0.179 mm **[Ans. : d]**

Q.22 Which of the tolerance values are obtained, when we use silk-screen resist method for maskant ?

a ± 0.013 mm | b ± 0.045 mm
c ± 0.077 mm | d ± 0.179 mm **[Ans. : c]**

Q.23 Which of the tolerance values are obtained, when we use photo resist method for maskant application ?

a ± 0.013 mm | b ± 0.045 mm
c ± 0.077 mm | d ± 0.179 mm **[Ans. : a]**

Q.24 Which of the following, are the main uses of etchants applied in chemical machining ?

a Good surface finish | b Uniform material removal
c Control intergranular attack | d All of the mentioned **[Ans. : d]**

Q.25 State whether the following statement is true or false about etchants.

"Etchants are used for controlling H_2 absorption in case of Ti alloys."

a True | b False **[Ans. : a**