AY : 2020-21
IV / II Sem : UNCONVENTIONAL MACHINING PROCESSES
NPTEL by prof Soutra paul

Course objectives : 1. The course aims in identifying the classification of UCMP's 2. To understand the principle mechanism of metal removal of various UCMP's
3. To study the various process parameters and their effect on the component machined on various UCMP's.
4. To understand the application of different processes.

UNIT-I : Need for non traditional m/cing methods. Classification of modern m/cing processes - Considerations in process selection, applications.
ultrasonic m/cing - Elements of the processes, mechanics of material removal, MRR process parameters economic considerations, applications and limitations.

Manufacturing classifications : 1. Primary m/f'ing : purpose
→ To impart basic shape and size
- Liquid stage forming processes - Casting
- Solid stage forming processes :
- all metal working processes - forging, rolling extrusions etc.
- Powder stage forming processes - powder metallurgy.
2. Secondary manufacturing :
- To impart final shape & size with tight control on dimension and shape.
- Mostly material removal processes

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Secondary manufacturing - classifications.

* Conventional manufacturing/machining processes
- Turning, Milling, Drilling, Shaping
- Broaching, Gear cutting, Grinding.

* Non traditional (conventional) Machining processes
- ultrasonic Machining (USM) 1, Electro chemical M/cing (ECM) 2
- Electro-discharge machining (EDM) (Thermal metal 3 removal processes), - Electron Beam M/cing & Laser (EBM & LBM) 4, - plasma machining 5 - Abrasive 6 Jet M/cing & A. Water Jet M/cing (WJM & AWJM)

Differences b/t Conventional and Non Conventional M/cing process

(ie) Characteristics of ,, ,,

In conventional M/cing process:
* Material removal due to application of cutting forces
* Energy domain - mechanical
* Macroscopic chip
* chip formation due to shear deformation
* Cutting tool is harder [than work piece]

In Non traditional M/cing process:

Material removal - chip formation (or) even no chip formation.

Ex: AJM - Micro scopic size

ECM - Electro chemical dissolution at atomic level

* Physical tool: May be absent
- LBM, m/cing is carried out by laser beam
- WJM, " is done by a high pr water Jet
- EDM, a physical tool is very much required, for ECM also.

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* Tool need not be harder than the work piece
  - EDM, copper is used as tool material to machine hardened steels
* Energy domain - not necessarily mechanical
  Different energy domains for m/cing
  - USM, AJM, WJM & AWJM - mechanical
  - ECM electro chemical dissolution
  - EDM Electro thermal energy.

Classification of NTM processes:

*. Mechanical processes:
  ↳ Abrasive Jet M/Cing, USM, WJM & AWJM, AFM, MAF
*. Electrochemical processes.
  ↳ Electro chemical m/cing (ECM), Electro chemical grinding
  Electro Jet Drilling (EJD)
*. Electro thermal processes (or) Thermo Electric: EBM, PAM Plasma Arc
  ↳ Electro discharge m/cing (EDM), Electro Beam m/cing, LBM
  Laser Jet M/Cing (LJM) i.e Electro-optical thermal process
* Chemical process: ECM: Electro chemical machining.
  ↳ Chemical Milling (CHM), photochemical Milling (PCM) etc. Bio chemical m/cing (BM)

Need for NTM process: 1. Exotic materials & lot of development in material side which can't be m/ced using conventional m/cing process, Innovative design & requirement, tighter tolerances, micro m/cing, economy.

2. Intricate shaped blind hole - e.g. square hole of 15X15 with a depth of 30mm using conventional it is difficult to drill a square hole.

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3. Difficult to m/c materials - eg: Same example as above in In conel (copper super alloys) Ti-alloys (or) Carbides → very easy to m/c by EDM, ECM.
4. Low stress grinding - Electrochemical Grinding is preferred as compared to conventional grinding.
5. Deep hole with small hole diameter - eg ϕ1.5 mm hole with l/d = 20.
6. M/c ing of composites

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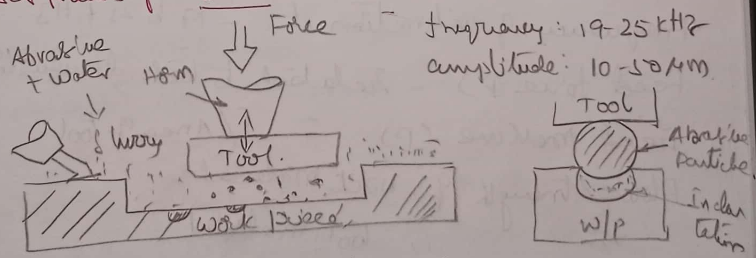
ULTRASONIC MACHINING: USM:

Instructional objective * Describe the basic mechanism of material removal in USM
* Identify the process parameters of USM
* ,, the M/cing characteristics of USM
* Analyse the effect of process parameters on MRR.
* Draw variation in MRR with different process parameters
* Develop mathematical model relating MRR with USM parameters.
* Identify & major components of USM equipment
* State the working principle of USM equipment
* Draw schematically the USM equipment
* List three applications of USM } At least
* ,, ,, limitation of USM

Process description of USM: Basic mechanism of MR in USM

frequency: 19-25 kHz
amplitude: 10-50 μm



* **Mechanisms of Material Removal in USM**: See back page →
* Tools vibration - Indentation by the abrasive grits
* Indentation - Hertzian Contact stresses - Cracks development just below the contact site
* Crack propagation and ultimately brittle fracture of work material
* Tool material - Indentation by grit should not lead to brittle failure

Thus tool materials are selected in such way that, they are tough, strong & ductile materials like steel, stainless steel and other ductile metallic alloys.

→ * USM for machining brittle work material
* Material removal primarily due to indentation by the hard abrasive grits on the brittle work material
* other than brittle failure due to indentation some work material removal may occur due to free flowing impact of the abrasives & related solid-solid impact erosion which is rather insignificant for mathematical modeling [Consider only indentation by harder abrasive particles]

Process variables: Amplitude of vibration (a_0) – 10–50 μm
Frequency of vibration (f) – 19 to 25 kHz.
Feed force (F) – related to tool dimensions
Feed pressure (P) = F/Area of tool
Flow strength of work material
" " tool material
Contact area of the tool – A
Volume concentration of abrasive in water slurry – C
Abrasive size – 15 μm – 150 μm
" material – Al_2O_3 – SiC – B_4C, Boron silicarbide
Diamond.

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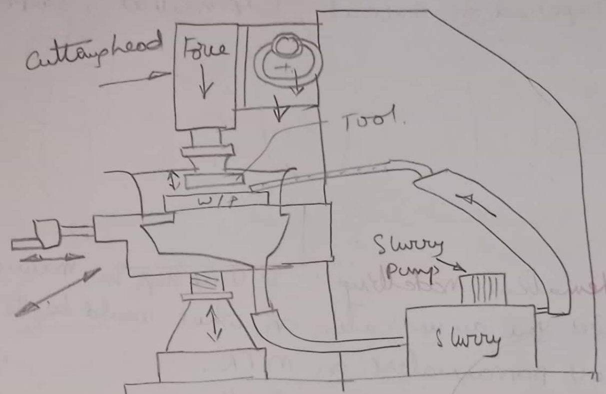
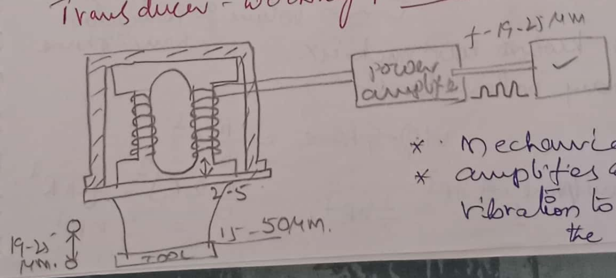
USM - Equipment:



USM - Equipment modules:

- Slurry delivery and returns system
- Feed mechanism to provide a downward feed force on the tool during machining
- 2 axis table with work piece holding device
- The transducer, which generates the ultrasonic vibration
  — piezoelectric eft & magnetostrictive effect } 2-5 μm.
- The horn (or) Concentrator, which mechanically amplifies the vibration to the required amplitude of 15-50 μm and accomodates the tool at its tip

Transducer - working principle:



Magneto strictive transducer
* popular
* robust amongst all

Horn (or) Concentrator
* Mechanical wave guide
* amplifies & Concentrates the vibration to the tool from the transducer

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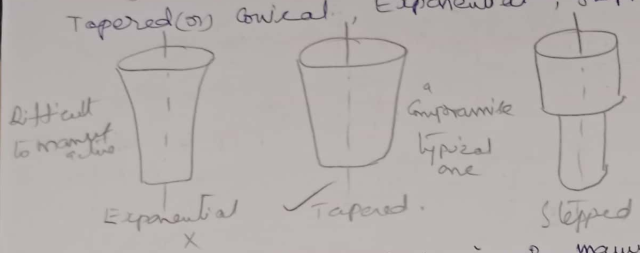
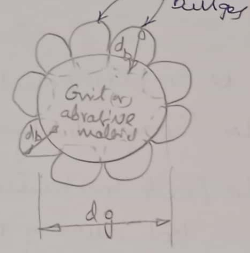
Horn (or) wave guides:

Tapered (or) Conical, Exponential, Stepped

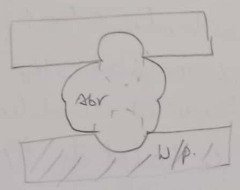


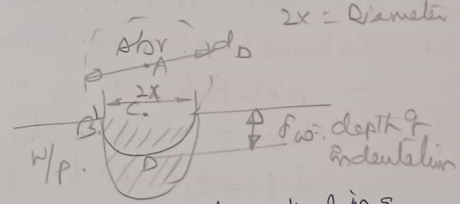
Mathematical Modelling: is very imp in manufacturing b/c it gives you an indication on what would be the effect of process parameters on MRR.



↳ Abrasive - Identical in shape and size.
↳ Spherical with Local bulges
↳ Grits characterised by d_g
↳ Local bulges - d_b = Local bulge diameter.

$d_b = \mu d_g^2$.





2X = Diameter

Amount of material removed in a single impact Γ_w : $\underbrace{\frac{2}{3}\pi x^3}_{\text{volume of particular hemisphere.}}$, where x = radius of sphere.

Now I should know how much is X and how many interactions

$$vol(\text{of}) \text{ sphere} = \frac{\pi}{6} d^3$$

$$\frac{\pi}{6}(2R)^3 = \frac{8}{6}\pi R^3 = \frac{4}{3}\pi R^3.$$

Volume of hemisphere $= \frac{1}{2}\cdot\frac{4}{3}\pi R^3 = \frac{2}{3}\pi R^3$.

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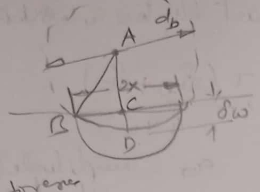


$AB^2 = AC^2 + BC^2$

$\left(\frac{d_b}{2}\right)^2 = \left(\frac{d_b}{2} - \delta_w\right)^2 + x^2$ neglecting δ_w^2 as $\delta_w << d_b$

$\therefore x^2 = d_b \delta_w$

however $d_g = 100\mu m$, $d_b = 10\mu m$ $\therefore$ δ_w^2 can be neglected

for single impact $\Gamma_w = \frac{2}{3}\pi (d_b \delta_w)^{3/2}$

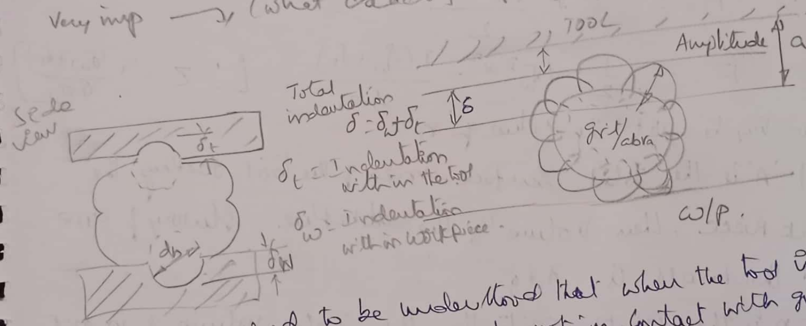
$MRR_w = \Gamma_w \, n.f.$ [MRR_w @ work piece]

So n is unknown & δ_w

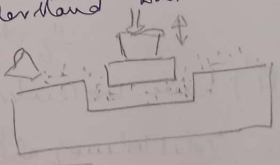
n = No. of grits available b/t tool & work piece.

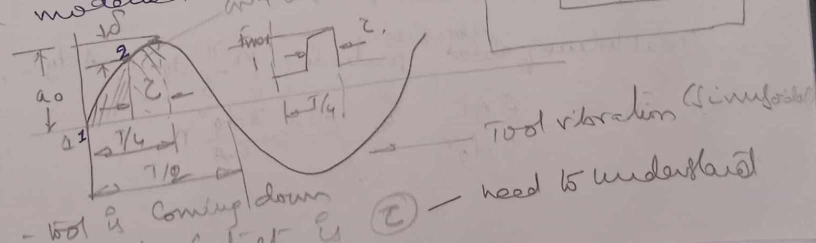
$\therefore MRR_w = \frac{2}{3}\pi n f (\delta_w d_b)^{3/2}$

Very imp → [what exactly happens]



it is required to be understood that when the tool is Coming down, the tool is totaly not in Contact with grit (or abrasive material. So we need to understand whether it can be modelled.





1-2 - tool is Coming down
after 2 only Contact is τ — need to understand

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Some part tool vibration there is no contact b/t tool & workpiece (or) abrasive material

$\therefore \frac{\delta}{a_0} = \frac{\tau}{T/4} \Rightarrow \tau = \frac{T\delta}{4a_0} = \frac{T(\delta_w + \delta_t)}{4a_0}$

a_0 : amplitude of vibration

Impulsive force (b/c of indentation)

$$I_f = \underset{\substack{\downarrow \\ \text{no of particles}}}{n} \cdot \underset{\substack{\downarrow \\ \text{How frequently interaction}}}{f} \cdot \underbrace{\tfrac{1}{2} F_{max} \cdot \tau}_{\text{Total force}}$$

Downward force $F = \frac{1}{2} F_{max} \cdot \tau \cdot n \cdot f$.

Max. force $F_{max} = \sigma_w \pi x^2$ [πx^2 = Area of force, Force indentation; σ_w = Force stress]

$\therefore F = nf \frac{\sigma_w \pi x^2}{2} \cdot \tau$

$F = \frac{1}{2} n f \sigma_w \pi x^2 \cdot \frac{T(\delta_w + \delta_t)}{4a_0}$ $\left[\because \tau = T\frac{(\delta_w + \delta_t)}{4a_0}\right]$

Now try to get the value of 'n'

If 'A' is the total surface area of the tool facing the work piece, then volume of the abrasive slurry of one grit thickness is $A d_g$.

If n is the no. of grits then the Total volume of n grits

$= \frac{\pi}{6} d_g^3 n$ $\left[\because \text{Volume of sphere is } \frac{\pi}{6} d_g^3\right]$

If I have concentration [% of abrasives in the slurry]

$\therefore$ Total volume of ~~abras~~ abrasive particles $n \frac{\pi}{6} d_g^3 = A d_g C$.

$\therefore n = \frac{6AC}{\pi d_g^2}$ & $C = \frac{\pi d_g^2}{6A} n$

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$$\therefore F = \frac{1}{2} n f \sigma_w \pi x^2 \frac{T(\delta_w + \delta_t)}{4 a_0}$$

where n = No. of abrasive particles available under the tool

f = frequency which is exciting on the w/c

σ_w = Flow strength of work piece

x = unknown

δ_w & δt = ,,

Let us find if there is a relation b/t δ_w & δ_t

It is very much imperative that $\frac{\delta_t}{\delta_w} = \frac{\sigma_w}{\sigma_t} = \lambda$ = Ratio of flow strength of work to flow strength of tool.

$$\therefore F = \frac{1}{2} n f \sigma_w \pi x^2 \frac{T}{4 a_0} \delta_w (1+\lambda)$$

$$F = \frac{1}{2} \frac{6AC}{\pi d_g^2} f \cdot \sigma_w \cdot \pi d_b \delta_w \frac{T}{4 a_0} \delta_w (1+\lambda) \quad [\because x = d_b \delta_w]$$

In above eqn everything is known except δ_w

$$\therefore F = \frac{3AC}{d_g^2} f T \frac{\sigma_w}{4 a_0} (\mu d_g^2) \delta_w^2 (1+\lambda) \quad [\because d_b = \mu d_g^2]$$

basically fT equals to 1

$$= 3AC(fT) \frac{\sigma_w}{4 a_0} (\mu) \delta_w^2 (1+\lambda)$$

(μ = grit parameter)

$$\therefore \delta_w^2 = \frac{4 a_0 F}{3 \mu A C \sigma_w (1+\lambda)}$$

$$\therefore MRR_w = \sigma_w n \cdot f$$

$$= \frac{2}{3} \pi n f (\delta_w d_b)^{3/2}$$

Taking $n = \frac{6AC}{\pi d_g^2}$ & $MRR = \frac{2}{3} \pi n f (\delta_w d_b)^{3/2}$

$$MRR = \frac{2}{3} \pi \frac{6AC}{\pi d_g^2} f (\delta_w d_b)^{3/2}$$

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$$= \frac{4AC}{d_g^2} f \left(\mu d_g^2 \delta_\omega\right)^{3/2}$$

$$= 4AC d_g \mu^{3/2} f \left\{\frac{4Fa_0}{3\mu AC\sigma_\omega(1+\lambda)}\right\}^{3/4}$$

$$\left[\because \delta_\omega^2 = \frac{4a_0 F}{3\mu AC\sigma_\omega(1+\lambda)}\right]$$

$$\therefore MRR = 4AC d_g \mu^{3/2} f \left\{\frac{4Fa_0}{3\mu AC\sigma_\omega(1+\lambda)}\right\}^{3/4}$$

Simplified eq^n for MRR

$$MRR \propto \frac{C^{1/4} \cdot A^{1/4} F^{3/4} a_0^{3/4} d_g f}{\sigma_\omega^{3/4}(1+\lambda)^{3/4}} \mu^{3/4}.$$

$$\propto \frac{C^{1/4} A P^{3/4} a_0^{3/4} d_g f.}{\sigma_\omega^{3/4}(1+\lambda)^{3/4}} \mu^{3/4}.$$

(where Force is converted to Pressure P)

MRR suggests

If we increase ↑C MRR↑ increases

" " ↑F " "

" " a_0 " "

" " d_g " "

" "

But if the material is strong (σ_ω) MRR↓

& $\lambda = \frac{\sigma_\omega}{\sigma_T}$, λ must be small when σ_T is strong

$\therefore \lambda\downarrow = \frac{\sigma_\omega}{\sigma_T\uparrow}$

Assumptions in Mathematical modelling:

1. All the grits are having the same shape & size
2. Local bulge & bulge diameters are same

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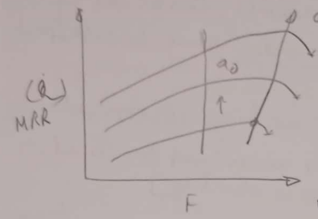
Effect of process parameters on MRR:

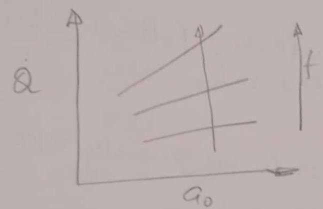


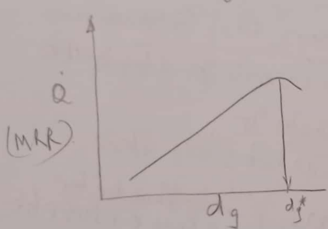
① As I increase Force F, MRR increase but beyond a particular point it starts ↓

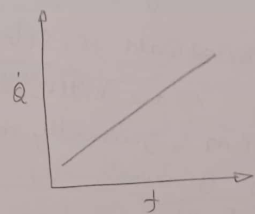
② Keeping force Constant if we increase a_0, MRR ↑

③ Beyond a particular force There is reduction which is b/c, beyond a particular force the tool would not be able to force the abrasive material towards the work piece. which is always be in Contact, such Contact b/t tool & work piece reduces MRR

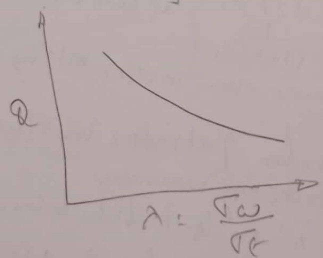
④ for same a_0, MRR increases [Keeping a_0 Const]

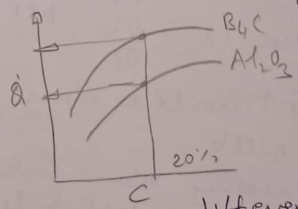






When d_g increases MRR increases upto Certain point, beyond MRR decrease b/c if amplitude of vibration is not increased along with d_g^* a point will that it is not getting enough power ie why MRR ↓





As $\frac{\sigma_w}{\sigma_t}$ increases, MRR decreases b/c TWR is more for flow strength of w/p is more, it is clear from Denominator $(1+\lambda)^{3/4}$ increases MRR ↓

Based on different abrasive particles for a given 'C' level for Al_2O_3 & B_4C MRR are given, so based on sharpness of abrasive particles (strength) The MRR will take place

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Applications: 1. used for machining hard & brittle metallic alloys, semi conductors, glass, ceramics, carbides etc.;
2. used for machining round, square, irregular shaped holes & surface impressions.
3. machining, wire drawing, punching (or) small blanking dies. [Note: USM is never used for steel which is ductile]
[Never used for large dies.

Limitations: Low material Removal Rate, Rather high tool wear, Low depth of hole, poor l/d ratio.

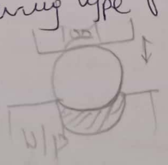
QUIZ

1. Which of the following material is not generally m/ced by USM:
✓(a) copper (b) Glass (c) Silicon (d) Germanium
Ductile material — All are brittle so USM is good for brittle
2. Tool in USM is generally made of
(a) Glass (b) Ceramic (c) Carbides ✓(d) Steel
Brittle

We know $X = \frac{\sigma_w}{\sigma_t}$, $MRR \propto f(\lambda) \propto \frac{1}{(1+\lambda)^{3/4}}$ } λ should be as less as possible

$\sigma_t \uparrow$ should be strong, more over in USM m/cing occurs for brittle.

3. Increasing volume concentration of abrasive in slurry would affect MRR in the following manner [as 'n' no. of particles increases]
– increase MRR
4. USM can be classified as the following type of NTM
(a) Electrical ✓(c) Mechanical
(b) optical (d) chemical



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Problems.

1. Glass is being m/ced at a MRR of 6 mm^3/min by Al_2O_3 abrasive grits having a grit dia of 150 μm. If 100 μm grits were used. What would be the MRR.

Sol: $$MRR \propto \frac{C^{1/4} F^{3/4} A^{1/4} a_0^{3/4} d_g f}{\sigma_w^{3/4} (1+\lambda)^{3/4}} \cdot \mu^{3/4}.$$

Thus $MRR = K d_g$ keeping all other variables unchanged

$$\therefore \frac{MRR_1}{MRR_2} = \frac{d_{g_1}}{d_{g_2}} \Rightarrow MRR_2 = MRR_1 \frac{d_{g_2}}{d_{g_1}}$$

$$MRR_2 = 6 \times \frac{100}{150} = 4 \text{ mm}^3/\text{min}.$$

2. For the above problem, from the initial setting the frequency is increased from 20 kHz to 25 kHz Det. new MRR

Sol: $MRR = Kf \quad \therefore MRR_{new} = \frac{f_{new}}{f_{old}} \cdot MRR_{old} = \frac{25}{20} \times 6 = 7.5 \frac{\text{mm}^3}{\text{min}}$

3. For the first problem, the feed force is increased by 50% along with a reduction in concentration by 70%. What would be the effect on MRR.

Sol $MRR = K C^{1/4} F^{3/4} \Rightarrow MRR_{New} = \left(\frac{C_{New}}{C_{old}}\right)^{1/4} \left(\frac{F_{New}}{F_{old}}\right)^{3/4} MRR_{old}$

$MRR_{New} = (0.3)^{1/4} (1.5)^{3/4} \times 6 = 6.02$ mm^3/min.

Almost no change in MRR

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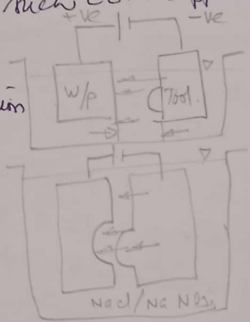
Electro chemical Machining

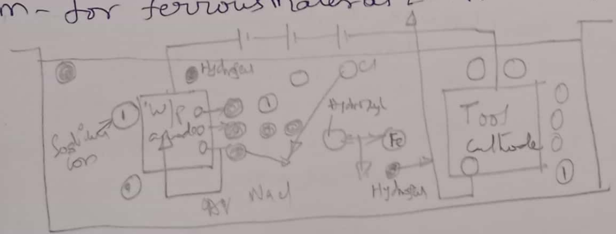
Instructional objectives

1. Identify ECM as a particular type of NTM
2. Describe the basic working principle of ECM
3. Draw schematically the basics of ECM
4. Draw tool potential drops
5. Describe MRR mechanism in ECM.
6. Identify the process parameters in ECM
7. Develop models for MRR in ECM
8. Analyse the dynamics of ECM process
9. Identify diff modules of ECM equipment
10. Draw schematics of four such ECM applications.



ECM - process.
- opposite of Electrochemical deposition
- Controlled anodic dissolution
- Tool - W/P - Conductive
- Tool - cathode
- W/P - anode
- Low potential
- High current
- M/cing gap to be maintained, - Electrolyte : NaCl / Na NO3

ECM - for ferrous material [Different types of materials]



Type : Direct current
Voltage : 2 to 35V

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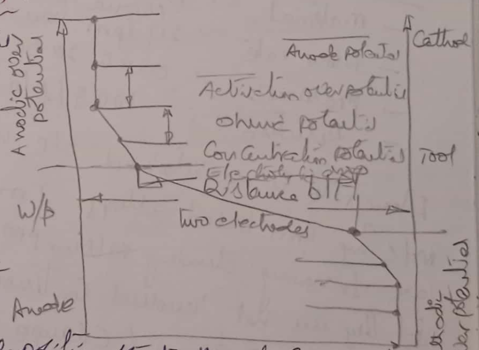
Sodium cloride & Sodium Nitrate are used as Electrolyte after applying DC Current.

At soon as current is passed, ferrous ions react with chlorine ions to form ferrous chloride and Hydrogen ions reach with ferrous ions to form ferrous Hydroxide. What happens to hydrogen ions, they go from w/p to to tool to form hydrogen gas

In summary In ECM, I have W/P (Anode), I have tool (cathode), the tool is connected to -ve terminal and the W/P is connected to +ve terminal. As a whole both W/P & tool are immersed in electrolytic solution (NaCl/ $NaNO_3$). I apply DC current and I have a vol (ape 2 to 35 V once the cell is switched on iron is come out from W/P to form $FeCl_2$ & $Fe(OH)_2$ & H_2 will evolve as gas. Due to controlled anodic reaction we will get

Potential drop in ECM:



first drop is anodic potential & Cathodic @ tool
secondly you require a bit of electrons passage b/t cathode & anode so activation over potential is required, then ohmic and finally concentration potential, once ECM (or) depletion starts there is concentration gradient near the electrodes
so finally there is 1 electrolytic drop to drive m/c (or) process.

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Process parameters: power supply:

- Type : DC
- voltage: 2 to 35V (low potential)
- Current: 50 to 10,000A
- Current density 0.1A/mm^2 to 5A/mm^2

process is controlled by current density not by current.

working gap : 0.1mm to 2mm. , overcut 0.2mm to 3mm

Feed rate : 0.5 to 15 mm/min ie tool has to feed with particular feed rate ie MRR is also be high according to feed rate.

Electrode material (tool material) : Copper brass, bronze and can be machined any material which can be electrically conductive irrespective of mechanical properties.

Surface finish Ra : 0.2 to 1.5 μm.

Electrolyte: plays a typical role in ECM

- material : NaCl & $NaNO_3$ (aqua sol) , Temperature 20°c - 50°c
- flow rate : 20 lpm per 100 A current
- pressure : 0.5 to 20 bar
- Dilution : 100 g/l to 500 g/l.

Flow rate is maintained b/c while m/cing if you are m/cing iron based alloys iron chloride and iron hydroxide are forming during m/cing process which are called sludges if they are not removed continuously, your molar concentration of electrolyte is going to change. Thus you need to have substantial flow rates, ~~for~~ for that you also require a mixture are required to remove sludges continuously from electrolyte

Dilution: 100g of NaCl is formed with 1kg of water (or) 1 lt " to get a particular electrolyte.

Characteristics of ECM :

Tool and work material – Electrically conductive
Atomic level dissolution
Surface finish excellent
Almost stress free m/ced surface [Almost no ~~res~~ residual stresses]
No thermal damage

Modelling of MRR : [MRR determines how fast you can m/cine, how fast is your m/cing time, which determine what is your productivity, even what is your profit rate] which leads to Techno-Economical viability of process.

– Material removal due to atomic dissolution of work material
– Electrochemical dissolution is governed by Faraday's law (I & II)
– Electrochemical dissolution (or) deposition
– ① Amount of electrochemical dissolution is proportional to amount of charge.
– ② Amount of material deposited (or) dissolved depends on electrochemical Equivalence (ECE) – ECE – ratio of atomic weight and valency.

① – $m \propto Q$

② $m \propto ECE \propto \frac{A}{V}$

① & 2 → $m \propto \frac{QA}{V} \propto \frac{ItA}{V}$

$\therefore m = \frac{ItA}{FV}$ [F = Faraday's Constant 96,500 Coulombs, A : Atomic wt, t = time, I in Amp]

$\therefore MRR = \frac{m}{t\rho} = \frac{ItA}{FVt\rho} = \frac{IA}{F\rho V}$ [for elements m/cing] (in mm³/s)

But in Engineering applications ~~elements~~ elements are not used only alloys (solid solutions of different elements exists nickel, iron), ex: steel, Incolenel,

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Modelling of MRR for alloys in ECM:

Atomic wt A_i, Valency ν_i, wt fraction α_i
For passing current of I for time 't', Γ_a volume of alloy gets dissolved, Total amount of dissolution of ith element
(or) ith element $m_i = \Gamma_a \rho \alpha_i$, $m_i = \frac{Q_i A_i}{F \nu_i}$

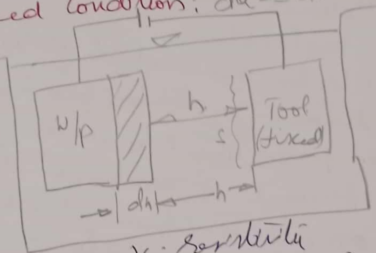
$$\Rightarrow Q_i = \frac{F m_i \nu_i}{A_i} = \frac{F(\Gamma_a \rho \alpha)_i \nu_i}{A_i}$$

Total charge $Q_T = It = \Sigma Q_i = F \Gamma_a \rho \Sigma \left(\frac{\alpha_i \nu_i}{A_i}\right)$

$\therefore$ MRR for an alloy $= \frac{\Gamma_a}{t} = \frac{I}{F\rho} \cdot \frac{1}{\Sigma \frac{\alpha_i \nu_i}{A_i}}$

MRR for an element $= \frac{m}{t\rho} = \frac{ItA}{F\nu t\rho} = \frac{IA}{F\rho\nu}$

Dynamics of ECM: No feed Condition: $dQ = I\,dt$



I is passed for time dt as Electrochemical dissolution of material of amount dh over an area 's' takes place

$I = \frac{V}{R} = \frac{V}{\frac{rh}{s}} = \frac{Vs}{rh}$ $\quad r$ = resistivity

[@ Time zero : No feed Condition]

$$MRR = \frac{IA}{F\rho\nu} = \frac{dh}{dt} \cdot s = \frac{dh}{dt} s$$ [material is contained or dissolved in the area s].

$$\therefore \frac{dh}{dt} = \frac{A_x}{F\rho\nu_x} \frac{Vs}{rh} \frac{1}{s} = \frac{A_x}{F\rho\nu_x} \cdot \frac{V}{rh} = \frac{c}{h}$$ constant [where x = equivalence]

$$\frac{dh}{dt} = \frac{c}{h}$$ where $c = \frac{A_x V}{F\rho\nu_x r}$ (for an element) (or) $c = \frac{V}{F\rho r \Sigma \frac{\alpha_i \nu_i}{A_i}}$ [for an alloy]

$\frac{dh}{dt} = \frac{c}{h}$ by integrating how h changes with time

$$\int_{h_0}^{h_1} h\, dh = c \int_0^t dt \Rightarrow h_1^2 - h_0^2 = 2ct$$

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At time progresses h increases in parabolic manner (from eq 11) had the MRR is constant the curve would have been straight line so that is not case, this

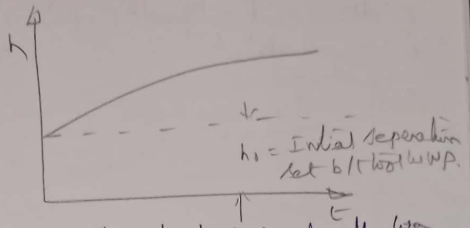

fig tells if there is no feed given to tool gradually, the distance b/t w/p and tool is increased and MRR is going to fall which is not a good thing, so we have to do something to maintain material removal, for that we give feed to tool.

Dynamics of ECM — Feed Condition:

Generally in ECM a feed (f) is given to the tool, so tool is forced for mm/sec so $\frac{dh}{dt} = \frac{c}{h} - f$

under steady state condition the gap is uniform i.e the approach of the tool is compensated by dissolution of work material $\Rightarrow \frac{dh}{dt} = 0 = \frac{c}{h} = f$

[To be set to 1.5

$\therefore h^* = $ S.S. gap $= \frac{c}{f}$

is it possible to set $h_0 = h^*$

$\frac{dh}{dt} = \frac{c}{h} - f$, $h' = \frac{h}{h^*} = \frac{hf}{c}$, $t' = \frac{ft}{h^*} = \frac{f^2 t}{c}$

$\Rightarrow$ Nondimensional $\frac{dh'}{dt'} = \frac{f/c}{f^2/c} \cdot \frac{dh}{dt} = \frac{1}{f}\frac{dh}{dt}$, $\frac{dh}{dt} = \frac{c}{h} - f$

$f\frac{dh'}{dt'} = \frac{c}{h' h^*} - f = \frac{cf}{h'c} - f$, $f\frac{dh'}{dt'} = f\left(\frac{1-h'}{h'}\right)$

$\frac{dh'}{dt'} = \frac{1-h'}{h'}$, $\int dt' = \int \frac{h'}{(1-h')} dh'$

Simulation for $h_0' = 0, 0.5, 1.5$

h_1' - Nondimensional final gap
1 - Nondimensional SS gap.
t' = Nondimensional time

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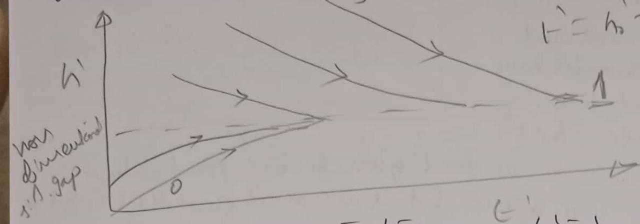
$$\int_0^{t'} dt' = \int_{h_0'}^{h_1'} \frac{h'}{1-h'}\, dh', \quad t' = \int_{h_0'}^{h_1'} -\frac{d(1-h')}{(1-h')} + \int_{h_0'}^{h_1'} d(1-h')$$

$$t' = h_0' - h_1' + \ln \frac{h_0'-1}{h_1'-1}$$



Thus irrespective of initial gap, $h' = 1$.

$$h' = \frac{h}{h^*} = \frac{ht}{c} = 1, \quad f = \frac{c}{h} = \frac{A_x V}{F\rho V_x r} \cdot \frac{1}{h}$$

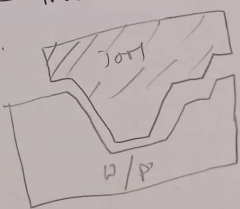
$$f = \frac{A_x}{F\rho V_x} \cdot \frac{V}{rh} = \frac{A_x}{F\rho V_x} \cdot \frac{I}{s} \quad \left[\text{as } I = \frac{V}{R} = \frac{V}{\frac{rh}{s}} = \frac{Vs}{rh}\right]$$

$$f = \frac{A_x}{F\rho V_x} \cdot \frac{I}{s} = MRR \text{ in mm/sec.}$$

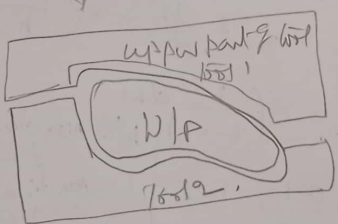
Applications: Die sinking, profiling & contouring

Emerging — Micromachining. — Very complicated geometry

(1) Die sinking:



They can be made



3D printing

insulation [To avoid problem of overcut

Drilling: Tool, Electrolyte

No electrochemical action here

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Quiz: 1. For ECM of Steel which is used as the electrolyte
(a) Kerosene ✓(b) NaCl (c) De ionised water (d) HNO_3

(a) ↓ medium used — Dielectric in EDM. Can't easily ionised so require much higher voltage to ionise it.

(b) ✓ both NaCl & HNO_3 can be used but, NO_3 reacts ~~with~~ violently. Can't control anodic dissolution

(c) It is not a tap water. It is also a dielectric medium, used in W-EDM (Wears)

(d) W-EDM (Wears)

(2) MRR in ECM depend on
(a) Hardness — Very imp in Conventional
✓(b) Atomic wt — [Electro.c.m follows Faradays law i.e $m \propto Q$ $\propto ECE \propto \frac{A}{V}$
(c) Thermal Conductivity — (Basic process is in thermal in nature then only T.C is used in Laser, EDM. Ie, plays a role
(d) ductility — in conventional as well as ~~NT~~ mechanical

③. ECM cannot be undertaken for
(a) Steel [Metallic alloy and it conducts electricity
(b) Nickel based a super alloy [T.C is very poor but thermally conductive.
✓(c) Al_2O_3 [is a ceramic, used as ceramic inserts Electrically insulator
(d) Titanium alloy (Even T.C is less, they are Good Conductor

④. Commercial ECM is carried out at a combination of: Low voltage and high current — b/c to do ionization in salt solution we require low voltage
why high current $m \propto Q = it$. i.e either you send high current within short time and low current within longer duration i.e sending high current within short time is Techno-economically viable.

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Problems: (1). In Electrochemical m/cing of pure iron (Fe) a MRR of 600 mm^3/min is required. Estimate current required.

$MRR = \dot{m} = \frac{m}{t} = \frac{AI}{F\nu}$, where $\dot{m}$ = material dissolved,
t = time
A = Atomic wt of element
I = Current, F = Faradays Constant, ν = valency of dissolution

$\therefore MRR = \dot{r} = \frac{m}{\rho t} = \frac{AI}{F\rho\nu}$ as $A_{Fe} = 56$, $\nu_{Fe} = 2$
$\rho_{Fe} = 7.8$ gm/cc.

$\therefore MRR = 600\ mm^3/min = 600/60\ mm^3/sec = 10\ mm^3/s$
$= 10 \times 10^{-3}$ cc/sec

$\therefore 10 \times 10^{-3} = \frac{56 \times I}{96500 \times 7.8 \times 2} \Rightarrow I = 268.8\ A$

(2). Composition of a Nickel Superalloy is as follows:

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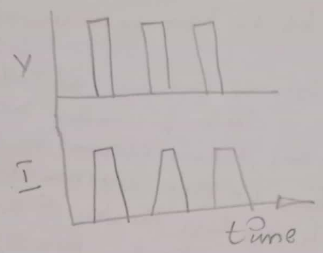
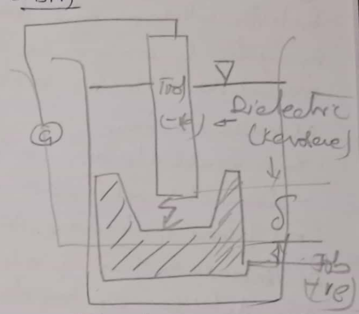
UNIT 3 – EDM

Instructional objectives:

Basics:





Tool and w/p are connected by a Generator (These waveforms as shown in V(vs) time & I(vs) time, They give rectangular wave form in V(vs)t & Trapezoidal wave form in I(vs) t. once) apply voltage there would be a spark b/t tool & w/p. Thermal energy of spark gradually d M/Cing on workpiece and the tool has to be lowered to get a square hole. Similarly any intricate M/Cing can be done using EDM

Mechanism of Material Removal: Both tool & w/p are electrically conductive, means there should be amount of free electrons. once electrical field & established free electrons will be plucked b/c they experience b/g electro static force. if the work function of tool material is less then electrons will come out b/c the presence of electrical field those electrons will come out they come out in large no's. which is once the " come out they after the electron had been come out called cold emission. electrons gets accelerate b/c tool within the space b/t tool & w/p, Now the medium b/t the w/p & tool is (−ve) & towards the w/p, electrons will not got free path, there is a collision is dielectric, electrons with dielectric molecules. of electron with dielectric field of molecules different things when collision with dielectric field of molecules & sufficiently energetic may happen By that time of electron is sufficiently energetic then they may ionise the die electric module.

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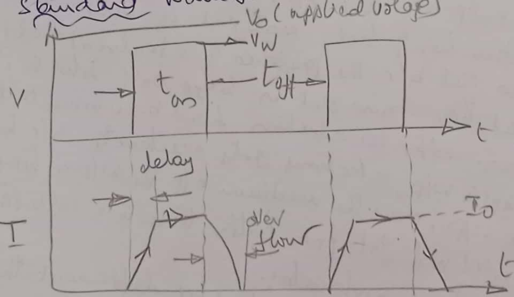
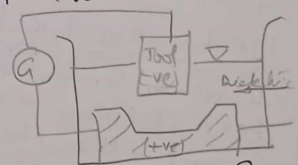
if it is not sufficiently energetic then they lead to elastic (or) inelastic collision. But some of the electrons will definitely energetic to ionize the dielectric molecules. once they ionises the dielectric molecules we have more ions as well as more electrons

There would also be secondary and tertiary ed collisions - plasma channel (plasma is a state of matter mostly with out of ions & electrons. so in that plasma channel there would be Avalanche motion of electrons i.e once plasma channel are establishes the resistivity is very less Therefore @ that pt of time we can see ~~(a)~~ that there is a spark. therefore EDM is also called Spark Erosion m/c. therefore w/p continuously impinge high energy electrons. so high energy electrons which converts ↑KE will develop high thermal energy which leads to localised melting leading to material removal

In EDM we don't apply the voltage continuously. in steps voltage is applied b/c we don't want arcs we want sparks so that throughout the work piece wherever the tool is present we get the m/cing

Standard wave form in EDM:





Initially voltage is applied b/t tool & w/p and is applied for a particular time (pulse on time (t_{on})) after some time (t_{off})

Current attains max value (not instantaneously) but after turn time once voltage is withdrawn current doesn't fall immediately but decreases gradually which is called overflow, one more parameter which is controlling EDM is level of max current i.e I_o

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Process parameters.

The open circuit voltage $- V_0 = 80$ V (around)
The working voltage $- V_w - 74 - 65$ V (")
The max. current $- I_0$
The pulse of on time $- t_{on}$ } ⇒ μs to ms
" off time $- t_{off}$ }

The gap, b/t w/pc & tool $- \delta$ (spark gap)
The polarity – straight polarity tool (–ve)
The dielectric medium
External flushing through the spark gap

Characteristic of EDM: ① The process can be used to m/c any work material if it is electrically conductive (as long as material is electrically conductive we can m/c any by using EDM) ~~etc~~ if it is not " free movement of electrons will not take place there would be other problem also)

② MRR depends on mainly thermal properties of work material rather than its strength & hardness B/c removal depends on $C/K/\rho/\theta_m$ [specific heat, thermal conductivity, material density & melting temp)

③ In EDM there is a physical tool and geometry of the tool is the +ve impression of the hole (or) geometric feature to be m/c-ned

④. The tool has to be electrically conductive as well. TWR once again depends on the thermal properties of the tool material

⑤ Though the local temp rise is rather high, still due to very small pulse on time, there is not enough time for the heat to diffuse and thus almost ~~no~~ no increase in bulk temp takes place, thus the heat affected zone is limited to 2 – 4 μm of the spark crater

However rapid heating & cooling & local temp leads to surface hardening which may be desirable in some applications.

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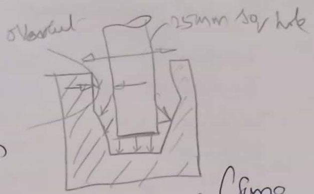

<u>Quality parameters</u> : Tapercut & over cut [not desirable] but they can be controlled & compensated

<u>Dielectric</u> * Material removal mainly occurs due to thermal evaporation & melting. As thermal processing is required to be carried out in absence of oxygen [some time it good lik in oxy acetylene process] so that the process can be controlled & oxidation avoided.

* oxidation often leads to poor surface conductivity (electrical) of the w/p hindering further m/cing. [If oxidation takes place which is not desirable in case of EDM Electrical conductivity decreases]
* Hence, dielectric fluid should provide an oxygen free m/cing environment.
* Further it should have enough <u>strong dielectric resistance</u> so that it doesn't breakdown electrically too easily but at the same time <u>ionise</u> when electrons collide with its molecule.
* More over, during sparking it should be thermally resistant as well.
* . kerosene & deionised water are used as
* . tap water [gets contaminated with salts] can't be used as it ionises too early & thus breakdown due to presence of salts as impurities occur.
* . Dielectric medium is generally flushed around spark zone.
* . It is also applied through the tool to achieve efficient removal of molten material.

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Tool Materials:

* Electrode not undergo much tool wear when it is impinged by +ve ions i.e for a square hole ⊠ leads to ◯ if tool wear exists.
* Localised temp rise has to be less. it is less if by tailoring (or) properly choosing its properties (or) even when temp increases there would be less melting
* Further, the tool should be easily workable as intricate shaped geometric features are m/c'ined in EDM.
* High thermal Conductivity - Electrons are cold emitted more easily and there is less bulk electrical heating i.e if conductivity is poor electrons will not come out.
* High thermal Conductivity - for the same heat load, the local temp rise would be less
* Higher density - for the same heat load and same tool wear by wt there would be less volume removal (or) Tool wear and thus less dimensional loss (or) inaccuracy
* High melting point - High melting pt leads to less tool wear due to less tool material melting for the same heat load.
* Easy manufacturability by Cost - cheap

Tool Material:

Graphite

Electrolytic oxygen free copper [$\rho \uparrow$, $k \uparrow$, elect $\uparrow$ but costly

~~M/c'd Modelling~~ Modelling & MRR

Material removal over crater $\Gamma_s = \frac{2}{3}\pi r^3$,

$E_s = VI\,t_{on}$., $E_w \propto E_s$, $E_w = kE_s$

$\Gamma_s \propto E_s \propto E_w$ $\therefore \Gamma_s = g E_s$

$MRR = \frac{\Gamma_s}{t_c} = \frac{\text{Material removal in a single spark}}{\text{cycle time}}$

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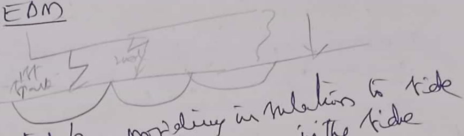
$= \frac{\Gamma_s}{t_{on}+t_{off}} \Rightarrow MRR = g\frac{VI\,t_{on}}{t_{on}+t_{off}} = g\frac{VI}{\left(1+\frac{t_{off}}{t_{on}}\right)}$

if $V\uparrow$, $I\uparrow$ & $t_{on}\uparrow$ — $MRR\uparrow$, if $t_{off}\downarrow$ $MRR\uparrow$.

product Quality issues in EDM

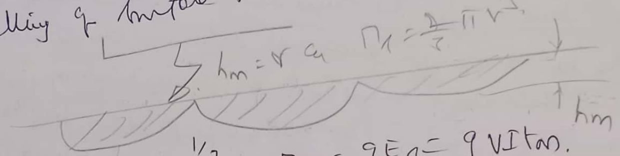


* Surface finish (h_m)
* over cut
* Taper cut

Taper cut can be prevented by modeling in relation to side of tool, b/c I can't prevent taper cut to occur in the side

I can't avoid over cut but can be prevented (In tool design as it can be compensated by taking increased dia of hole.

Modelling of surface finish in EDM



$r = h_m = \frac{3}{2}\Gamma_1^{1/3}$ & $\Gamma_1 = gE_1 = g\,VI\,t_{on}$.

$\therefore h_m \propto (\Gamma_1)^{1/3} \propto E_1^{1/3} \propto (VI\,t_{on})^{1/3}$

Productivity & Quality:

$MRR\uparrow = g\frac{VI\,t_{on}}{t_{on}+t_{off}} = g\frac{VI}{1+\frac{t_{off}}{t_{on}}}\uparrow$.

$h_m\uparrow \propto [VI\,t_{on}]^{1/3}$.

if t_{off} decreased I can also simultaneously increase h_m

* Reduce t_{on} but simultaneously reduce t_{off} as well
* But t_{off} not be so less that arcing occurs & (m/cing becomes unstable;

The above two points are indicating that $h_m\downarrow$ without sacrificing MRR.

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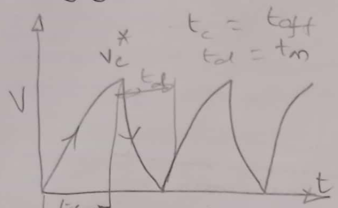
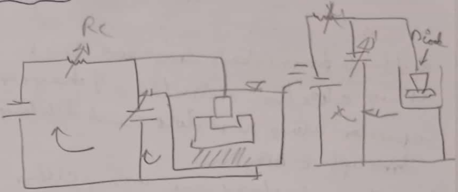
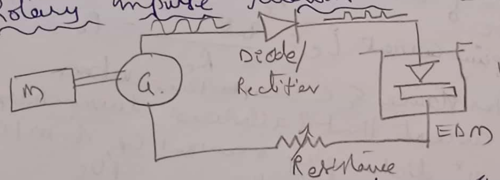
RC type EDM Generator:

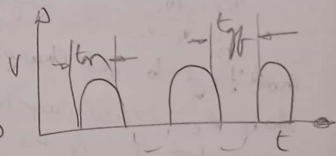




when potential difference is applied, gradually capacitor charge reaching voltage to V_c^*. During charging EDM is not going on i.e. $t_c = t_{off}$, during discharging the current is flowing through the EDM M/C through the spark gap $\therefore t_d = t_{on}$. It works on simple thing, I gradually charge capacitor which gets discharged through the M/C.

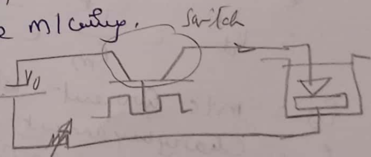
Rotary impulse generator with Rectifier:



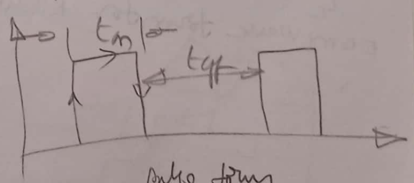


when motor runs the generator, a sinusoidal wave is generated when this sinusoidal wave passes through my diode, only the part is allowed and -ve would not be allowed, what we get once it passes through a pulse, only half cycle presently. During this half cycle, I have m/cining.

Electronic pulse Generator (Good one)



The pulse generator (⎍⎍⎍) is triggering EMF through switch.
The adv. is I can design any value of t_{on} & t_{off} whatever I desire.
In previous Rotary, I don't have any control over pulse generation, but here I do have control for t_{on} & t_{off}.



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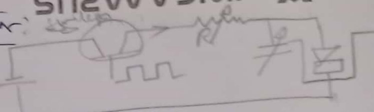
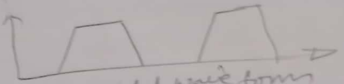
Hybrid electronic Pulsogenerator:



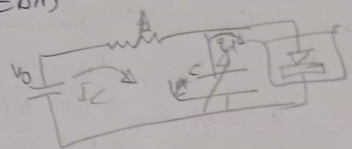
" " " differs from Transistor one that using electronic switch, I charge cap capacitor using resistors and discharge through EDM.



Trapezoidal wave form much better than ignore

Most of industries are using either ~~Hydr~~ Hybrid (or) RC type

Working principle of RC type EDM



During charging capacitor is getting charged

$\therefore C\frac{dv}{dt} = \frac{V_0 - V_c}{R}$

$\frac{dv}{V_0 - V_c} = \frac{1}{RC}dt$ @ $t=0, v=0$

$\therefore \int_0^{V_c^*} \frac{dV_c}{V_0 - V_c} = \frac{1}{CR_c}\int_0^{t_c} dt \Rightarrow -\frac{t_c}{R_c} = \left|\ln(V_0 - V_c)\right|_0^{V_c^*}$

modified to get charging current $i_c = \frac{V_0 e^{-t/R_cC}}{R_c} = i_0 \cdot e^{-t/R_cC}$

where R_c = charging resistance & C = capacitance value

i_0 is the current that is allowed during charging

~~at~~ ~~for~~ discharging a current i_d to m/c capacitor @ a value of V_c^* would have resistance of (R_m), $i_d = \frac{V_c}{R_m} = -C\frac{dV_c}{dt}$

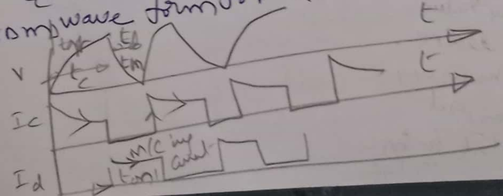
$\therefore \int_{V_c^*}^{V_d^*} \frac{dV_c}{dV_c} = -\frac{1}{CR_m}\int_0^{t_d} dt$, $\therefore \frac{t_d}{CR_m} = \ln\frac{V_d^*}{V_c^*}$

$\therefore V_d^* = \frac{V_c^*}{R_m} \cdot e^{-t_d/R_mC} \Rightarrow i_d = \frac{V_d}{R_m} = \frac{V_c^*}{R_m} \cdot e^{-t/R_mC}$

i_d = m/c current which flows through EDM m/c

i_c = charging current " " does it

EDM wave form for RC Generator: during charging voltage gradually increases & during discharging voltage decrease



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Cycle Time & Frequency:

$V_c^* = 0.716\, V_0$ for max. power o/p

$$t_c = -\frac{R_c C}{\ln\left(1 - \frac{V_c^*}{V_c}\right)} \quad \& \quad t_d = -\frac{R_m C}{\ln\left(\frac{V_d}{V_c^*}\right)}$$

$$\therefore f = \frac{1}{t_c + t_d} = \frac{1}{\frac{R_c C}{\ln\left(1 - \frac{V_c^*}{V_c}\right)} + \frac{R_m C}{\ln\left(\frac{V_d}{V_c^*}\right)}}$$

Spark energy:

$$E_s = \int_0^{t_d} i^2 R_m \, dt = \int_0^{t_d} \frac{V_c^{*2}}{R_m^2} R_m e^{-\frac{2t}{R_m C}} dt$$

finally $E_s \cong \frac{1}{2} C V_c^{*2}$

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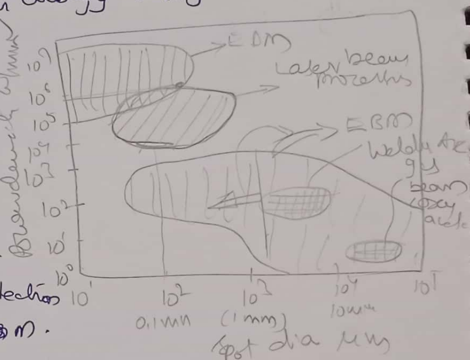
UNIT-4: EBM & LBM

EBM & LBM are under Electro thermal processes.
These two processes though belong to ,, they can also be described as Electro-optical-Thermal processes, why because both in EBM & LBM, we generate a beam of Electrons with high velocity and high energy e's in case of Laser beam m/c we a beam of photons, Thus they can also be classified as Ele-optical-Thermal.

→ They are basically High energy density processes.

eg: In case of LBM, the spot size is very small leading to high power density

→ Both EBM & LBM are equipment intensity processes i.e Equipment is heart of the process. In EBM, Electron beam gun generates Electron beam which is heart of EBM.



→ EBM Gun: It operates under vacuum.
The whole structure whatever shown is under vacuum.
The cathode is made up of either tungsten W (or) Tantalum T & a filaments type. potential difference is applied a/c this filaments, so that the filament temp goes around 2500°C at such high temp and moreover under vacuum. There is emitting thermo ionic electrons, moreover this particular cathode is highly -vely biased. after the cathode you have Bias grid which is imp in construction of EBM gun, b/c it controls the flow of electrons. This bias grid is typically -vely biased so that electrons can't collected on it rather they are concentrated

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Just following biased grid, you have + vely biased anode
b/t the cathode & anode electrons are accelerated. As the electrons
pass this particular anode section, they achieve a high velocity
which is half of the velocity of light. So when they are passing
this particular anode section they are highly energetic.
→ Following the anode you have two more things one is magnetic
lenses [function is to discharge the same function of any lens which
is to concentrate (or) focus a beam of light], here we don't have
a beam of light, we have beam of electrons. After magnetic lens
we have an aperture [Just like an aperture of an optical camera]
But the purpose is different, whatever stray electrons are available
the aperture will capture those ~~stray~~ stray electrons so that the electron
beam emerges from magnetic lens section, they are very very
concentrated and focused ones. Further down the line, you
have an electro magnetic lens which focuses beam on the
electrode (w/p) and below you have deflector coils which can
deflect E-Beam so that you can correct if you are not getting
hold w/p. Two more are Illumination & Telescope which
are used simultaneously to allign the electron beam with the
w/p. To left there is vacuum gauge port to measure the pr.
and to right there is a diffusion pump port, it is a vacuum pump
which maintaining vacuum within EBM chamber. The level
of vacuum is 10^{-4} - 10^{-6} torr (1 torr = 1 mm of Hg = 0.0012 bar). If they are
not maintained under vacuum, you don't have thermoionic
emission. Even if there is a electron emission, electron will
be accelerated collide with air molecules, and beam would not
to that extent. There are too many collisions with air molecules
and E-beam loses their energy. This is the reason

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EBM gun (or) EBM m/cing is carried out under vacuum. under deflector coils you have slotted disc (Purpose is whenever you are m/cing with electron beams M.R occurs b/c of vaporisation and melting. those vapors should not enter my electron beam (or) should not abstruct, the optical window of electron beam gun. So there is a slotted disc and they are synchronised with electron beams and always it will allow the electron beams to interact with the w/p, but it would not allow any vapor of work// to abstruct windows of the electron beam. * In EBM the gun is operated in pulse mode, unlike in electron beam welding where it is opered on continuous mode. so how it is operated on puls mode. In Bias grid we have already mentioned that it is -vely biased which is not continuous it is in pulse mode as this bias grid is in pulse mode, grid controls the flow of electrons. So whenever it is in appropriate bias it will allow the flow of electrons and otherwise not allow flow of electrons.

EBM - modules of Electron beam Gun:

↳ Cathode Cartridge - tungsten (or) tantalum (filament)
↳ High voltage supply - Cathode -vely charged
Bias grid - (pulsed) to get pulse mode operation
Anode -
magnetic lens - aperture - stray electrons - focussed/concentrated beam
Electromagnetic coils (focussing lens)
Deflector coils
Lighting system & tele scope for alignment
Rotating slotted disc [protect the beam not to damage]
Vacuum pumps - Diffusion pump.

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Diffusion pump: A small boiler containing some oil, below which heater, as we heating the oil, oil vapor will produce start going up. To evolve those oil we have a structure called set of nozzles and a port pump is connected backing line which is in term connected to a rotary pump, is also a vacuum pump where vacuum is not maintained so high. So what happens, when we heat the oil, oil vapor comes out, as they reach first set of nozzle ~~they~~ the moment is diverted and come out as high velocity jet and similarly they come out from other upward sections also. D. Pump consists of series of cooling coils which helps in condensation of oil vapor in nice manner and entrainment of any residual air. Through these cooling coils cold water is passed.

EBM – Mechanism of M. Removal:

↳ Thermoionic electrons

Acceleration of electrons due to anode potential $= \frac{1}{2}C$ (vel. of light)

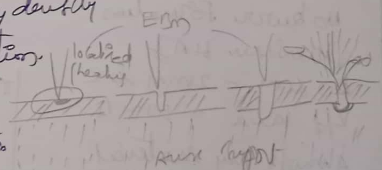
High velocity beam of Electron

Shaping and focussing of the electron beam

Impingement of high velocity electron beams on the w/p

Spot size 10 – 100μ – high energy density

Heating, melting & vaporisation.



once the electrons impinged on w/p

Localised heating by focussed electron beam, then gradual formation of hole by penetrating melt – vaporisation front and finally it penetrates till auxiliary material ie severe melting & vaporis. of auxiliary material. B/c of A.M, expulsion of any takes place upto auxiliary material at the top by high vapor pr of auxiliary material molten material

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Process parameters of EBM :

(V_a) Accelerating voltage : B/t my anode a cathode I have acc. voltage ie 100kV

(I_b) Beam Current – 250 μA – 1A – Current flowing b/t cathode & w/p

(t_{on}) Pulse duration – 50 μs – 50 ms : How often you put pulse b (cos of) bias grid, only during pulse you are allowing to impinge on w/p

Energy/pulse – 100J / pulse

power per pulse

Lens current – Determines up to what extent the electron beam focussed which determines spot size

Spot size – 10 μm – 500 μm

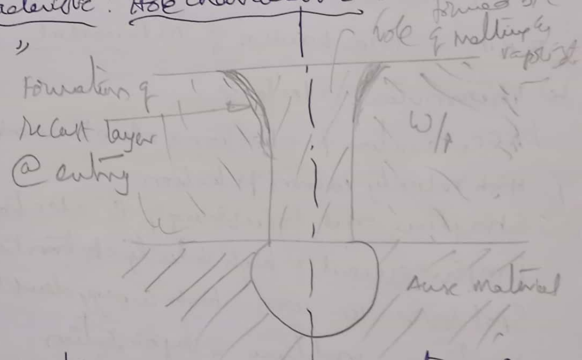
$$\text{power density}, P_d = \frac{\frac{1}{2} m_e v_e^2}{\frac{\pi}{4} d_s^2} = \frac{V_a I_b t_{on}}{\pi/4\, d_s^2}$$

Basically indicates how fast len of m/c

$$P_d = \frac{\text{K.E of electron beam}}{\text{spot size area}} = \frac{\text{mass flow rate of electron}}{\text{spot size dia}}$$

EBM – M/Cing characteristic : Hole characteristic :-

shape of hole is "



Plane of focussing

Reverse Tapering

Auxiliary support

Recast layer

No burr formation

Minimum HAZ

Dia – 2mm dia

l/d ratio – 10~15

Almost any material

Shallow angle drilling 20° –

* Typically there is a formation of recast layer @ entry [resolidified layer]
* When vapor & molten material expelled from w/p to o/side there is resolidification takes place @ entry. ie when there is no heat in put (or) no pulse, there can be resolid. @ entry b/c of which there would be tapering

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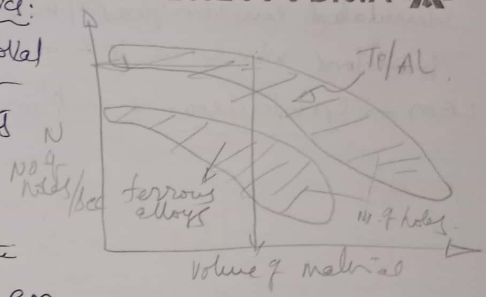
EBM speed characteristics:
for same material removal I can mk faster in case of Ti/Al, definitely Al melts @ lower temp than Ti, faster as Ti is concerned b/c of Thermal conductivity & you can mk @ faster rate



LBM

LASER: Light Amplification by Stimulated Emission of Radiation

Albert Einstein – 1917, Industrial laser – 1960s
Wave length – 0.5 to 70 micron.
power density – as high as 1MW/mm²
Absorption of Laser Energy – very interesting that it (Laser) absorbed by material leading to rapid rise in Temperature there by melting & Evaporation & Material Removal
So MRR is similar to EBM process in the sense that once Laser is absorbed there is rapid rise in temp, melting and evaporation and material removal.

LBM – working principle; Spontaneous absorption
working principle of Laser depends on stimulated emission. Atom is absorbed & spon. absorption & emission takes place in Nano sec However there is stimulated absorption leading meta stable absorption.

spontaneous emission:
Time duration
Stimulated absorption
Meta-stable state of Electron
Time duration – micro to ms
population inversion
stimulated emission
Phase coherency – Temporal & Spatial

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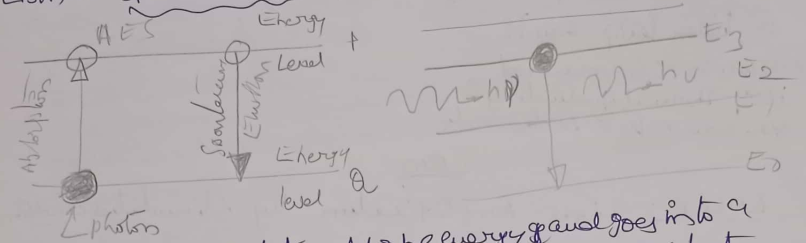
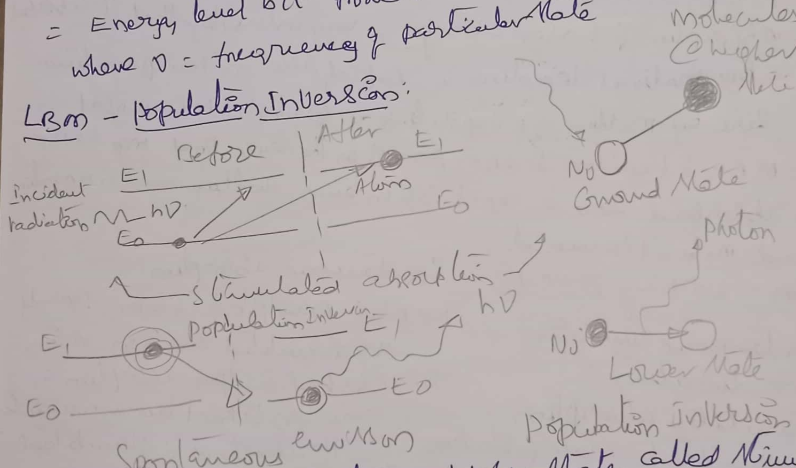
Stimulated emission gives phase coherency with beam of photons which are both in temporal & spatial mode

LBM – Spontaneous absorption & Emission:



Photon @ ground state absorbs energy and goes into a HES (Higher energy state and doesn't stay @ HES but comes back to ground state emitting photons. Here energy hν = Energy level b/t ground state & HES., $E_1 - E_0 = h\nu$ where ν = frequency of particular state

LBM – Population Inversion:



We can also put electrons in higher state called stimulated
The energy of photon moves from ground state to higher energy
This electron would come down once again to lower energy level. and energy is released as hν

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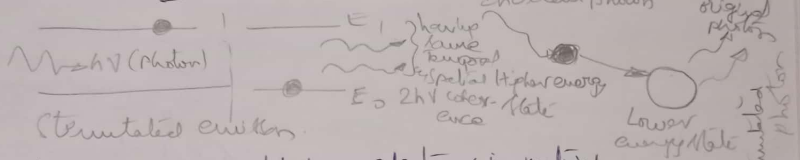
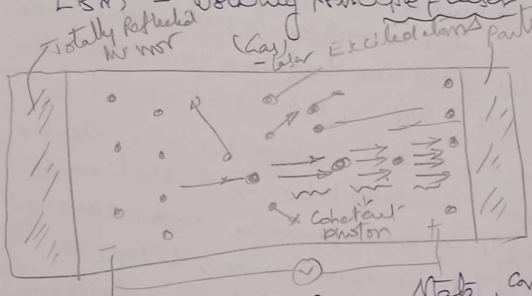
LBM – Stimulated Emission:



Already we have lot many electrons in material which is population inversion and generally electrons are not in higher state. Now stimulated emission ~~forming to~~ leading to formation of Laser.

LBM – Working Principle of Laser:



(Gas laser – Gas inside the tube, Excited by Electrical discharge with one cathode & one anode, what happens, they would be going to higher energy state, come down and finally large coherent photons coming out and no. of photons are released. when the photon strikes mirror (partially) it comes back and combines with higher energy photons, Therefore at the end they form coherent photons.

LBM – Laser Types and Lasing Medium:

Gas Lasers – Helium – Neon, Argon – CO_2 etc – wave length 0.63 μm

Solid State lasers – Ruby which is chromium – Aluminium Alloy with wave length 0.7 μm

Nd – glass lasers having a wave length of 1.64 μm

Nd – YAG (Yerritium – Al – Garnet) laser with 1.06 μm

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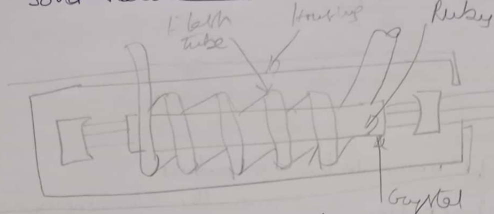
Solid state <u>laser</u> : LBM.



Around Ruby rod
I have a Flash tube
which pumps energy
within the Ruby rod
so that electrons @
ground state will come to higher energy state.

<u>Working of Solid state</u> : Flash tube pumps energy within the ruby rod creating population inversion. Hour it is run, there is a capacitor [charged and discharged] the discharging time a discharge time is determined by resistor, and there is switch which initiates first emission and we get the laser beam which interacts with a w/p. : <u>Ref figure in PPT</u>

LBM - Gas laser : <u>Ref fig in PPT</u> : In a gas laser also we need population inversion. In a laser tube, we send continuously CO_2, N_2, He where CO_2 is my lasing medium. N_2 & He are used as supporting gases. To left we have anode & to right we have cathode, so when we apply high voltage electrical discharge is developed b/t these two electrodes. So energy " " pumps the electrons from ground state to higher energy state, so as they come out forming a ~~lab~~ laser beam. As the photons release lots of heat energy coolant ~~for~~ cools the gas. and also loose internal cooling is provided by N_2 & He.

The length of tube here we maintain is 100W/1m length so to develop 100m length. We go for high carbon laser to get 100m length without going to 100m length which is done by folded ~~to~~ gas laser - <u>Ref fig</u>:

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So we have series of individual gas laser tubes, so once photon pass thru one tube reaching turning mirror amplifies wattage so that we achieve desired wattage

LBm - Mechanism of Material Removal: Ref fig in ppt.
In case of CO_2 laser used for cutting / melting we ~~have~~ have Gas Assist which enhancing the material removal
Laser coming out from particular tube is stimulated to next possibly produces 200W by passing thru turning mirrors, so we have laser tubes in series one upon another with folded. So once again you have power supply producing 400W gas flow lines (not shown) & Two fold tubes only shown but you can have 5 fold, 6 fold like to increase the power down gas

LBm: MRR: Ref fig: Absorption of laser Energy, Rapid rise in Temp, melting & Evaporation, Material Removal Gas Assist. Here also the energy of photon of laser beam is absorbed by work material so increasing the temperature This increase in temp will lead to melting of material & evaporation depending on work material leading to material removal In case of CO_2 laser which is mainly used for cutting action which can also be called melting action we can use gas assist for enhancing the MR.

Laser - characteristic: Most Common lasers are Nd-YAG ~~Yttrium~~ ~~Yttrium~~-Al-Garnet

B/c of O/P like (10-1000W) when laser is operated on Beam mode like pulsed the peak power achieved is 400KW

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LBM - Advantages

↳ Micro holes can be drilled in difficult to m/c material

↳ Though laser processing is a thermal processing but heat affected zone specially in pulse laser processing is not very significant due to shorter pulse duration.
B/C of continuous mode incase of CO_2 HAZ is much but for pulsed mode due pulse HAZ is less.

* . In laser m/c ing there is no physical tool. Thus no m/cing force (or) wear of tool takes place. for example in case of ECM & EDM we have physical tool

* . Large aspect ratio (both dimension, form and location) in laser drilling can be achieved along to with acceptable accuracy (or) dimensions, form (or) location.

LBM - limitations : High initial capital cost - in CO_2 & Nd-YAG High maintenance cost ; Not very efficient process b/c from energy point of view it is not very very " but m/cing point of it can m/c many material. presence of HAZ - specially in as assist CO_2 laser cutting. Owing to thermal issues (both chance to limitation) not suitable for heat sensitive materials say for example (Ref figure) we have a particular color called resists in laminated structure easily effected by heat of laser

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UNIT - V : PAM :

working principle : you have a Non Consumable tungsten electrode covered by water cooled constricting nozzle which is again covered by shielding nozzle. -ve power supply is given to electrode & +ve to w/p. so plasma gas is ionised and made electrically conductive. In PAM arc is constricted generated in a constrictive nozzle, instead of diverging the temp which arc of was 28000°c, so in arc, it is concentrated over the w/p which is used to this process a high velocity Jet of high temp gas is used to melt & remove material from w/p. This high velocity & hot gas is also known as plasma Jet.

* When a gas (or) air is heated at a temp of more than 5000°c, then it will start getting ionized into +ve ions, -ve ions & neutral ions.

* When the gas (or) air is ionised its temp reaches from 11000°c to 28000°c & this ionised gas is called plasma.

* The gas (or) air is heated with arc & plasma produced by heating gas is used to remove material from the w/p. & the whole process is called plasma arc m/cing.

* In this process, a high velocity of high temp air is used to remove material from w/p by melting it. So the gas used in plasma arc m/cing is chosen according to the metal which is used as the w/p.

* The plasma machining is used for cutting alloy steels, stainless steel, aluminium, nickel, copper & cast iron.

* what is plasma : When a solid is heated to the melting pt it turns into liquid and then a liquid is heated, it turns to gas. If a gas is heated to nearly 2000°c, the molecules will dissociate into separate atoms. if the temp is further raised to nearly 3000°c, electrons of atoms of gas will be displaced and the atoms are ionised and this ionised gas is called plasma

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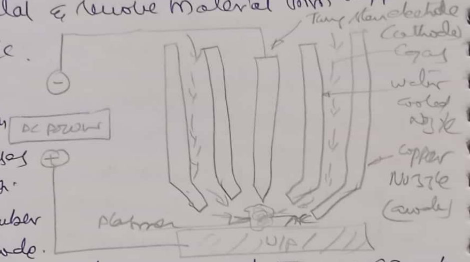
Working principle: Cont; PAM process uses ionised plasma to transfer heat. The plasma is obtained by forcing gas thru an electric arc generated b/t cathode & anode. This high temp plasma jet melts the metal & remove material from W/P

Components of Plasma Arc mlc.

Plasma Gun: Different gases like nitrogen, hydrogen argon (or) mixture of these gases are used to create plasma. This plasma gun has a chamber which has a tungsten electrode.



This tungsten electrode is connected to -ve terminal & nozzle of the plasma gun is connected to +ve terminal of the DC power supply. The required mixture of gas is supplied to the gun.
A strong arc is produced b/t the anode & cathode.
After that, there is a collision b/t the electron of the arc and the molecules of gas and due to this collision, gas molecules get ionised and heat is generated.

W/P: Different materials can be worked using this plasma arc mlcing. Different metals like aluminium, magnesium, carbon, stainless steel & alloy steels can be worked using this process.

Construction of PAM: The plasma arc cutting torch carries a tungsten electrode fitted in the chamber. This electrode is connected to the -ve terminal of the DC power supply. For PAM a plasma gun is required which has a chamber. This gun has a tungsten electrode fitted inside the chamber. This tungsten electrode is connected to -ve terminal of DC power and acts as a cathode. At the bottom of chamber, there is a copper nozzle that is connected to a +ve terminal of the DC power supply and acts as an anode.

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The rest of the chamber is made of insulating material and acts as insulator. Gas enters the chamber thru a small passage present at the right side of the chamber.
The cathode and the anode remain cool despite the hot gases passing thru them as they are water cooled. Water circulation is present around ~~or~~ the torch.

<u>Working</u>: when a D-C power is supplied to the circuit a strong arc is produced b/t the cathode (electrode) and the anode (nozzle). After that, gas is supplied to the chamber. This gas can be hydrogen, Nitrogen, Argon or mixture of these gases chosen acc. to metal to be worked. The gas used in the process is heated using the arc produced b/t the cathode & anode. producing a very high temp from 11000°c to 28000°c.

As the arc comes into ~~ac~~contact with the gas, there is a collision b/t the electron of the arc & molecules of the gas and the molecules of the gas will dissociate into separate atoms.
Due to the high temp's generated from the arc, electrons from ~~the~~ some atoms will be displaced and atoms are ionised (Electrically charged) and the gas turns into plasma. As the gas is ionised a large amount of thermal energy is liberated. This high velocity gas is directed towards w/p to remove the material.

<u>Benefits of electrodes [Generation of arc]</u>: Increases the temp of ionized gas, makes the beam almost 11%. & Increases the velocity of the gas. As the plasma jet reaches the w/p, the plasma melts the w/p and the high velocity gas blows away the molten metal. (4) used for rough turning of very hard materials

<u>Advantages</u>: (1) Hard as well as brittle metals can be easily mlced.
(2) Gives a faster production rate
(3) Small cavities can be m/cned using this process with good dimensional accuracy ↑

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(5) Also used in m/c's that are used to repair Jet engine blades

Disadvantages : 1. Equipment used in PAM is very costly.
2. Metallurgical changes take place on the surface of W/P
3. The consumption of inert gas is high.
4. Also oxidation and scale formation takes place, shielding is required.

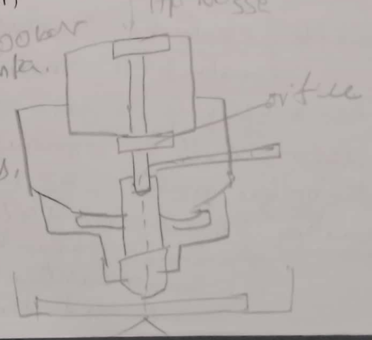
Applications of PAM : 1. It is used in mill applications
2. used in nuclear submarine pipe systems
3. used in welding rocket motor case
4. " " of stainless steel tubes.
5. It is used in profile cutting.

UNIT - 6

WJM & AWJM : Instructional objectives

Diff. b/t WJM & AWJM
will different WJM and AWJM systems
" " modules of AWJM "
" Application of AWJM
" disadv of AWJM
" Materials that can be processed by AWJM
Describe function of different elements of AWJM
" Mechanism of Material removal
Develop models for mechanism of material removal
Identify parameters related to product quality
" Limitations of AWJM

WJM & AWJM : Diff.



WJM - pure
WJM - with stabiliser
AWJM - entrained - 3 ϕ
Abrasive - water & air
AWJM - suspend - 2 ϕ
abrasive & water : Direct pumping
Int " "
By pass "

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General Experimental Conditions:
orifice - Sapphires - 0.1 to 0.3 mm, Abrasive flow - 0.1 to 1.0 kg/m
Focussing tube - WC - 0.8 to 2.4 mm, Stand off distance - 1 to 2 mm
pressure - 2500 to 4000 bar., M/c impact angle - 60° to 90°
Abrasive - garnet & olivine - #125 to #60.
Transverse speed - 100 mm/min to 5 m/min.
Depth of cut - 1 mm to 250,

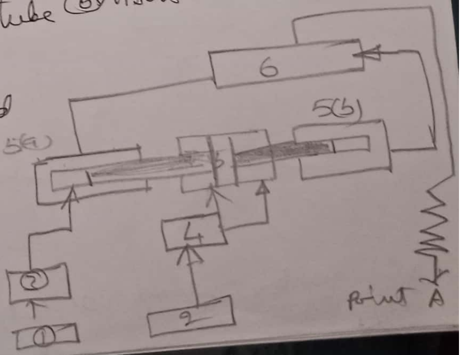
Advantages - AWJM: Extremely fast set up and programming
very little fixturing for most parts, m/c virtually any 2D shape
on any material - very low side forces during m/cing - Almost
no heat generated on your part

Materials: AWJM [Steels - Non ferrous alloys - Ti alloys, Ni alloys
polymers - Honey combs - Metal Matrix Composite - Ceramic
Matrix Composite] WJM [Concrete - Stone - Granite - Wood - Reinforced
plastics - Metal polymer Laminates - Glass fibre Metal Laminates]

Applications: WJM Paint removal - cleaning - cutting soft materials
- cutting frozen meat - Textile, Leather industry - Mass immunisation
- surgery - peening - cutting - pocket milling - drilling -
Turning - Nuclear Plant Dismantling.

Different Modules - entrained:
LP booster pump - Hydraulic unit - Additive Mixer - Intensifier
Accumulator - flexible transmission line - on-off valve - orifice -
mixing chamber - focussing tube (or inserts) - Catcher - CNC table
Abrasive metering device.

AWJM - Schematics - entrained



1. LP Booster 2. Hydraulic drive
3. Additive mixer 4. Direction Control
5. Intensifier, 5(a) LP Intensifier
5(b) HP Intensifier
6. Accumulator

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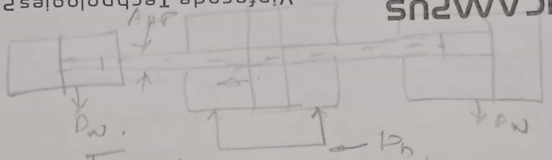
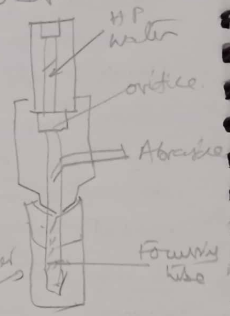


Intensifier - extracted

$$P_w = \frac{P_h A_{LP}}{A_{HP}} = 100 \times 40 = 4000 \text{ bar}$$

Jet Former (or) cutting Head - extracted



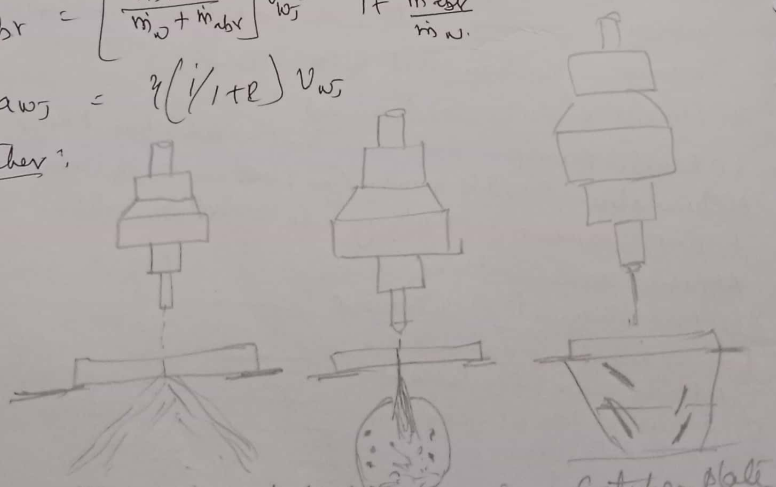
Mixing process:

Mixing process - Modelling:

$$v_{abr} = \left[\frac{\dot m_w}{\dot m_w + \dot m_{abr}}\right] v_{wj} = \frac{1}{1 + \frac{\dot m_{abr}}{\dot m_w}} v_{wj} = \left(\frac{1}{1+R}\right) v_{wj}$$

$$v_{awj} = \eta \left(1/1+R\right) v_{wj}$$

Catcher:



(a) Water basin (b) Steel/WC/Ceramic balls Catcher plate TiB_2

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