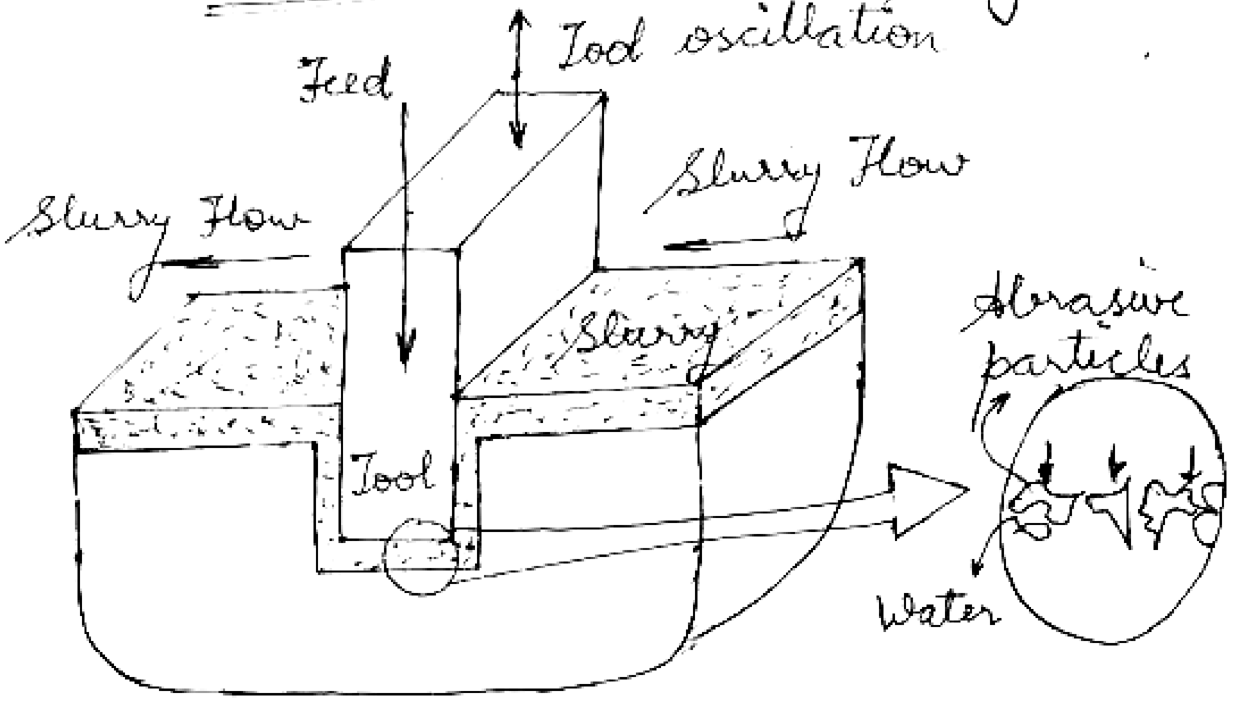
1. # Ultrasonic Machining (USM)



Introduction / Working principle:

— USM is mechanical material removal process or an abrasive process used to erode holes or cavities on hard or brittle w/p. by using shaped tools, high frequency mech. motion and an abrasive slurry.

— Brittle w/p's such as single crystal, glasses, and polycrystalline ceramics.

— Increasing complex operations to provide intricate shapes and w/p profiles.

— USM is a NTM process, in which abrasives contained in a slurry are driven against the work by a Tool oscillating at low amplitude (25-100μ and high frequency (15-30 kHz).

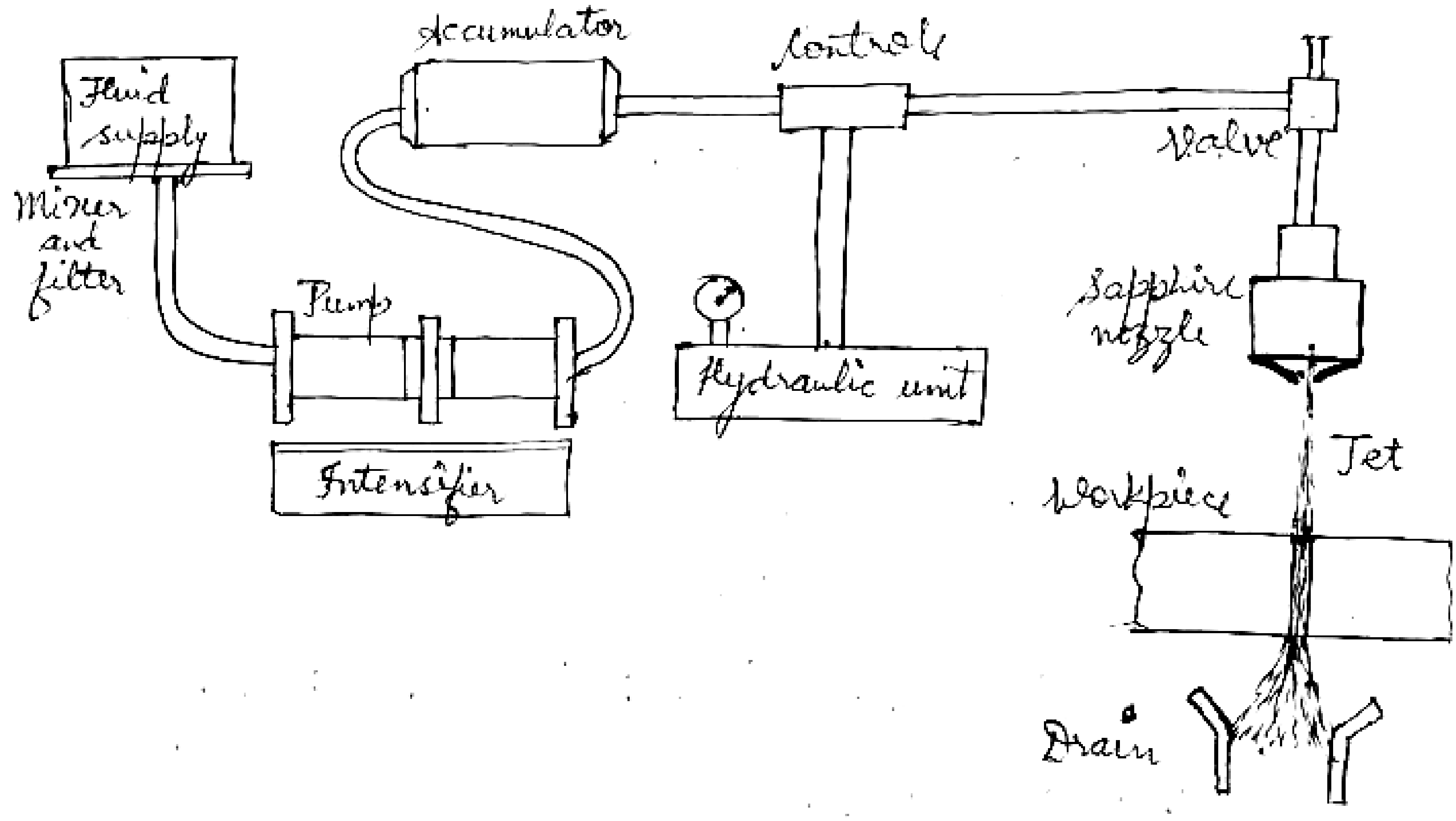
- The process was first developed in 1950's.
- The basic process is that a ductile and tough tool is pushed against the work with a constant force.
- A constant stream of abrasive slurry passes b/w the tool and the work (gap is 25-40 μm) to provide abrasives and carry away chips.
- The majority of the cutting action comes from an ultrasonic (cyclic) force applied.
- The basic components to the cutting action are believed to be:
  - brittle fracture caused by impact of abrasive grains due to the tool vibration.
  - cavitation induced erosion.
  - chemical erosion caused by slurry.
- Material removal primarily occurs due to the indentation of the hard abrasive grits on the brittle work material. Other than this brittle failure, material removal may occur due to ~~indentation due to~~ free flowing impact of the abrasives

Advantages of USM:

— USM is a non-thermal, non-chemical, creates no change in the microstructures, chemical or physical properties of the w/p and offers virtually stress-free machined surfaces.
— Any material can be machined regardless of their electrical conductivity.
— especially suitable for machining of brittle materials.
— Machined parts possess better surface finish & higher structural integrity.
— No burrs and no distortions of w/p.

2(a) <u>Water Jet Machining (WJM)</u>

<u>Equipment and process:</u>



— It works on the principle that, when a jet of water at a very high pressure and velocity is made to strike the w/p, K.E. of the jet is transferred into mechanical work.

— WJM is a form of <u>micro erosion</u>. It works by forcing a large volume of water thro' a small orifice in the nozzle.
The extreme pr. of the accelerated water particles contacts a small area of the

and acts like a saw and cuts a narrow groove in the material.

The equipment consists of:

(a) Pressure generation system:

It consists of pump, electric motor, intensifier and accumulator with necessary controls and valves.

(b) Intensifier:

It increases the pressure of water to high values, so that it can be used for cutting operations. It generates high pr. by means of piston-cyl. arrangement. The high-pr. water is then fed into the accumulator.

(c) Accumulator:

An accumulator (reservoir) is simply a pressure vessel, which stores the high-pr. water. This storage is necessary, since the energy is not required continuously.

(d) Valves and controls:

They are incorporated at suitable locations for their usual purpose.

(e) Tubing:

It is used to transport the high-pr. water from one system component to another.

(f) Nozzle:

It is used to convert the high-pr. water to a high-velocity jet.

Because it may be subjected to cracking and erosion, as jet of water comes out of the nozzle at a high velocity, it is made from a hard material like sintered diamond, WC or sapphire etc. to prolong its use.

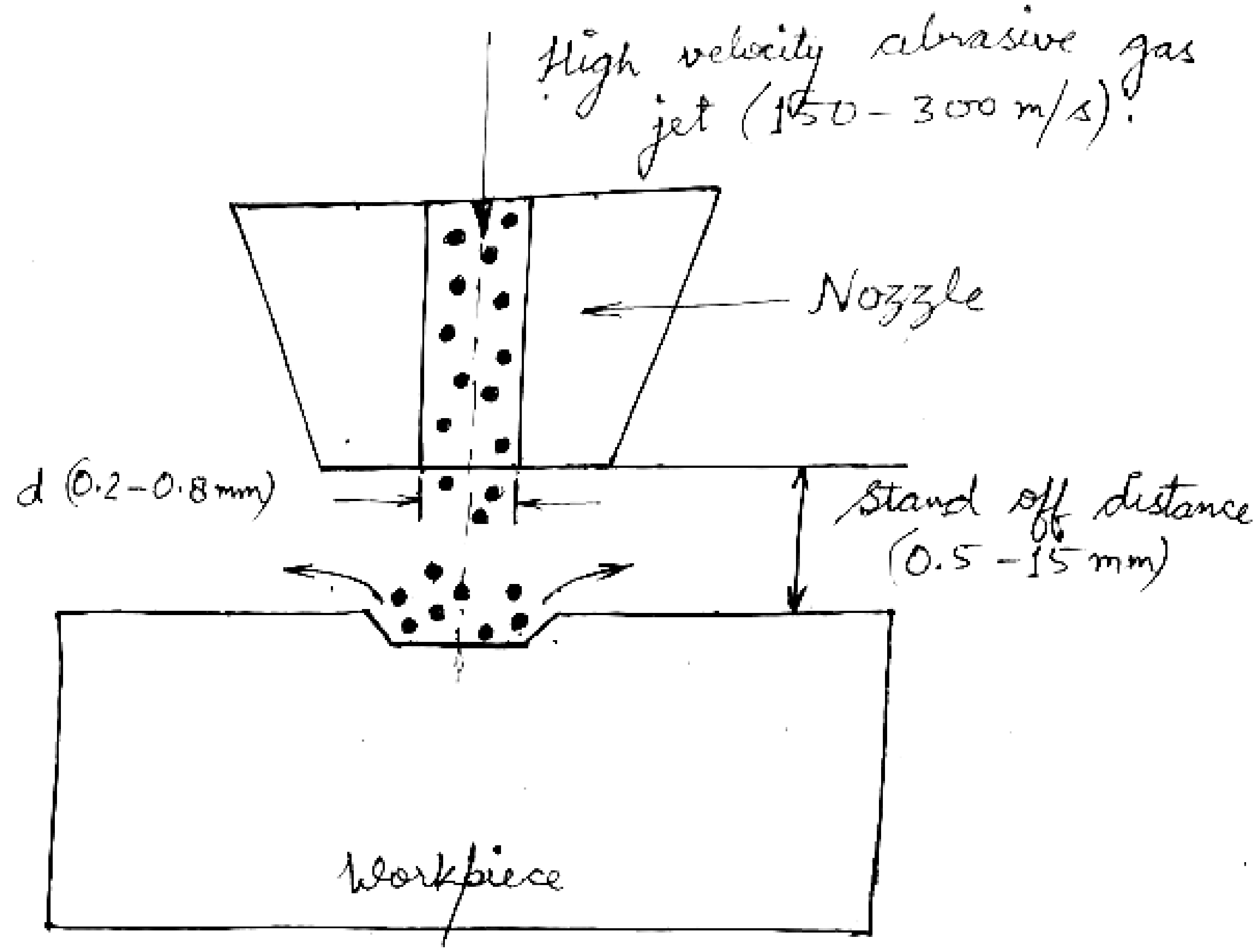
WJM operation:

— Firstly, filtered water from the water tank enters the hydraulic intensifier, where its pr. is increased to a high value. Then high-pr. water is supplied to the accumulator (reservoir).

— To begin the operation, the valve is switched to ON position. The high-pr. water enters the nozzle, where the whole of the pr. energy is converted to K.E.

— Then high velocity jet of water forcing out of the nozzle is directed towards the worksurface. As the jet strikes, K.E. of the jet is transformed into mechanical work.

2.(b) Abrasive Jet Machining (AJM)



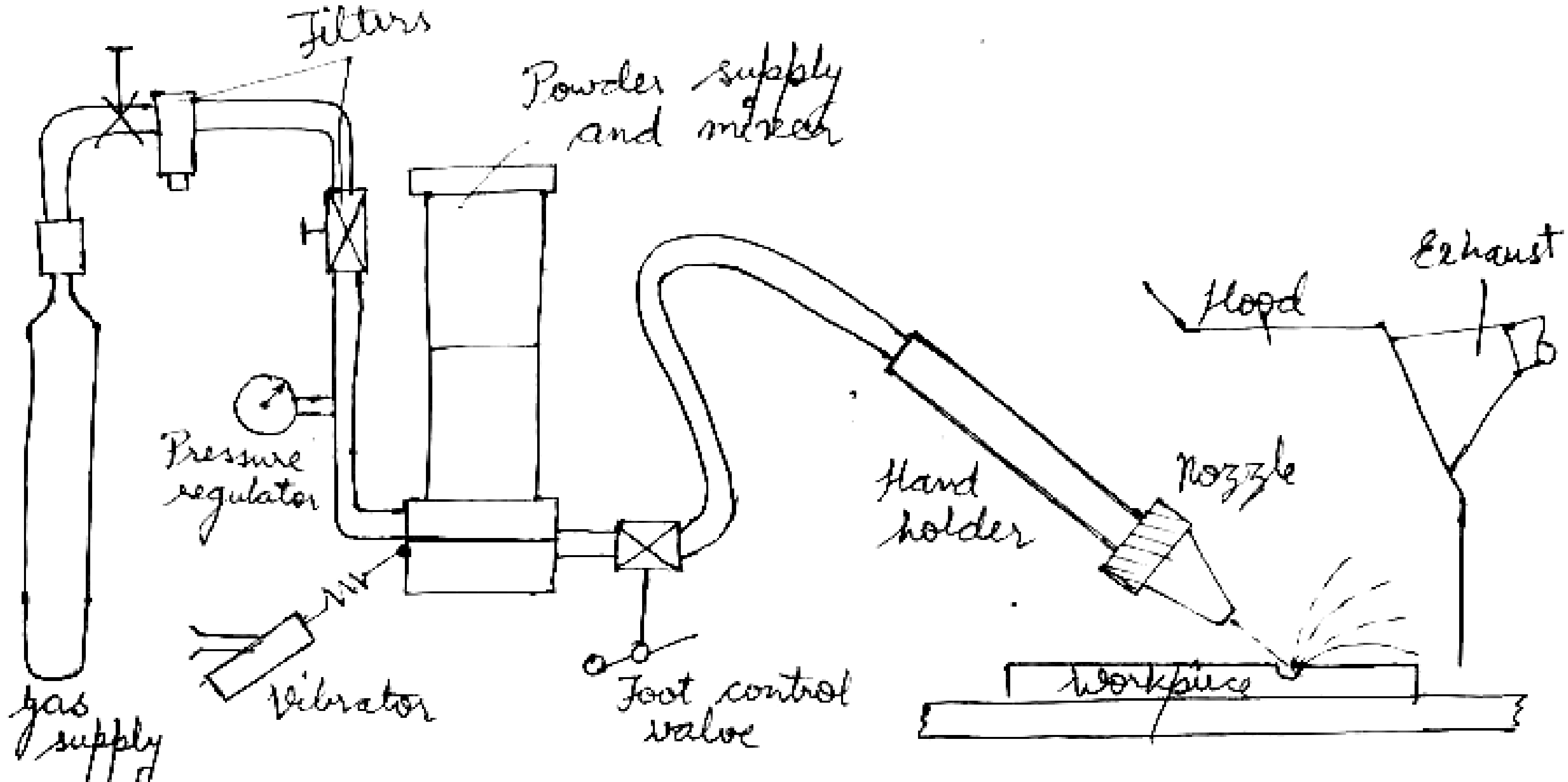
Introduction / Working Principle:

— In AJM, abrasive particles are made to impinge on the work material at a high velocity. The jet of abrasive particles is carried by carrier gas or air.

— The high velocity stream of abrasive is generated by converting the pressure energy ~~into~~ of the carrier gas or air to its K.E. and hence high velocity jet.

- The nozzle directs the abrasive jet in a controlled manner onto the work material, so that the distance between the nozzle and the w/p and the impingement angle can be set desirably.
- The high velocity abrasive particles remove the material by micro-cutting action as well as brittle fracture of the work material.
- AJM is different from standard shot or sand blasting, as in AJM, finer abrasive grits are used and the parameters can be controlled more efficiently providing better control over product quality.
- In AJM, generally, the abrasive particles of around 50 μm grit size would impinge on the work material at velocity of 200 m/s from a nozzle of I.D. of 0.5 mm with a stand-off distance of around 2 mm.

AJM equipment:



— In AJM, air is compressed in an air comp^r. and compressed air at a pressure of around 5 bar is used as the carrier gas.

Gases like CO_2, N_2 can also be used as carrier gas which may directly be issued from a gas cylinder. Generally oxygen is not used as a carrier gas (it may oxidize the surface).

— The carrier gas is first passed thro' a pr. regulator to obtain the desired working pr. To remove any oil vapour or particulate contaminant the same is passed thro' a series of filters. Then the carrier gas enters a closed chamber known as the mixing chamber The abrasive particles enter the chamber from a hopper thro' a metallic sieve. The sieve is constantly vibrated by an electromagnetic shaker.

— The mass flow rate of abrasive (15 gm/min) entering the chamber depends on the amplitude of vibration of the sieve and its frequency.

Then the abrasive particles are carried by the carrier gas to the machining chamber via an electromagnetic on-off valve, and the machining is carried out as high velocity abrasive particles are issued from the nozzle onto a w/p traversing under the jet.

— The preferred abrasive materials involve Al_2O_3 and SiC at small grit sizes. The grains should have sharp edges and should not be reused as the sharp edges are worn down.

— AJM is used for deburring, etching and cleaning of hard and brittle metals, alloys, and non-metallic materials (eg: germanium, Si, glass, ceramics, and mica).

5(a) Selection of NTM processes:

The following ten attributes/criteria that usually influence the NTM process selection decision:

(a) Tolerance & surface finish (TSF): It reflects the machining capability of a NTM process, how closely it can maintain the tolerance and achieve the required surface finish on the work material. Surface finish is measured in terms of centre line avg. (CLA) or Ra value (in microns).

(b) Power requirement: It relates with the power rating of the machine/equipment for a particular NTM process in kW.

(c) Material Removal Rate (MRR): It measures the amount of material (in mm^3) removed from the w/p by a particular NTM process per unit of time.

(d) Cost (C): It considers the initial acquisition cost and investment needed for installation of a NTM process based machine/equipment for a given machining application.

(e) Efficiency (E): It is the ratio of output energy available to remove the required amount of material from the w/p to the input energy for a given NTM process.

(f) Tooling and fixtures (TF): It takes into account the cost of tooling and fixtures that need to be replaced from time to time in a particular NTM process.

(g) Tool consumption (TC): It is associated with the cost of tool changes for a particular NTM process, although it does not consider the time req. for such tool changes.

(h) Safety (S): It is related to the safety of m/c operators for a specific NTM process. It also considers the toxicity, machining medium contamination, and other adverse and hazardous effects of the NTM processes.

(i) Work material (M): It mainly caters with the fact that how easily a particular NTM process can machine a given material and how often the NTM process can be used for that material

3.(b) Applications of WJM:

— It is used to cut non-metallic materials like glass, epoxy, graphite, leather and many other brittle materials.

— Used in cutting printed circuit boards for electronic applications.

— Removal of surface irregularities, burrs, or in cleaning and descaling operations.

4. Need for NTM:

— Conventional machining sufficed the requirement of the industries over the decades. But new exotic work materials as well as innovative geometric design of products and components were putting lot of pressure on capabilities of conv. machining processes to manufacture the components with desired tolerances economically. This led to the development of NTM processes in the industry as efficient & economic alternatives to conv. ones.

— With development of NTM, they are often the first choice and not an alternative to conv. ones.

— The following examples are provided where NTM processes are preferred over the conv. machining processes:

- Intricate shaped blind hole — eg: square hole of 15 mm x 15 mm with a depth of 30 mm.
- Difficult to machine material — e.g: Ti alloys, carbides

- Low stress grinding — Electrochemical grinding is preferred as compared to conv. grinding.
- Deep hole with small hole dia. – eg: ϕ 1.5mm hole with $l/d = 20$.
- Machining of composites.

NTM Processes

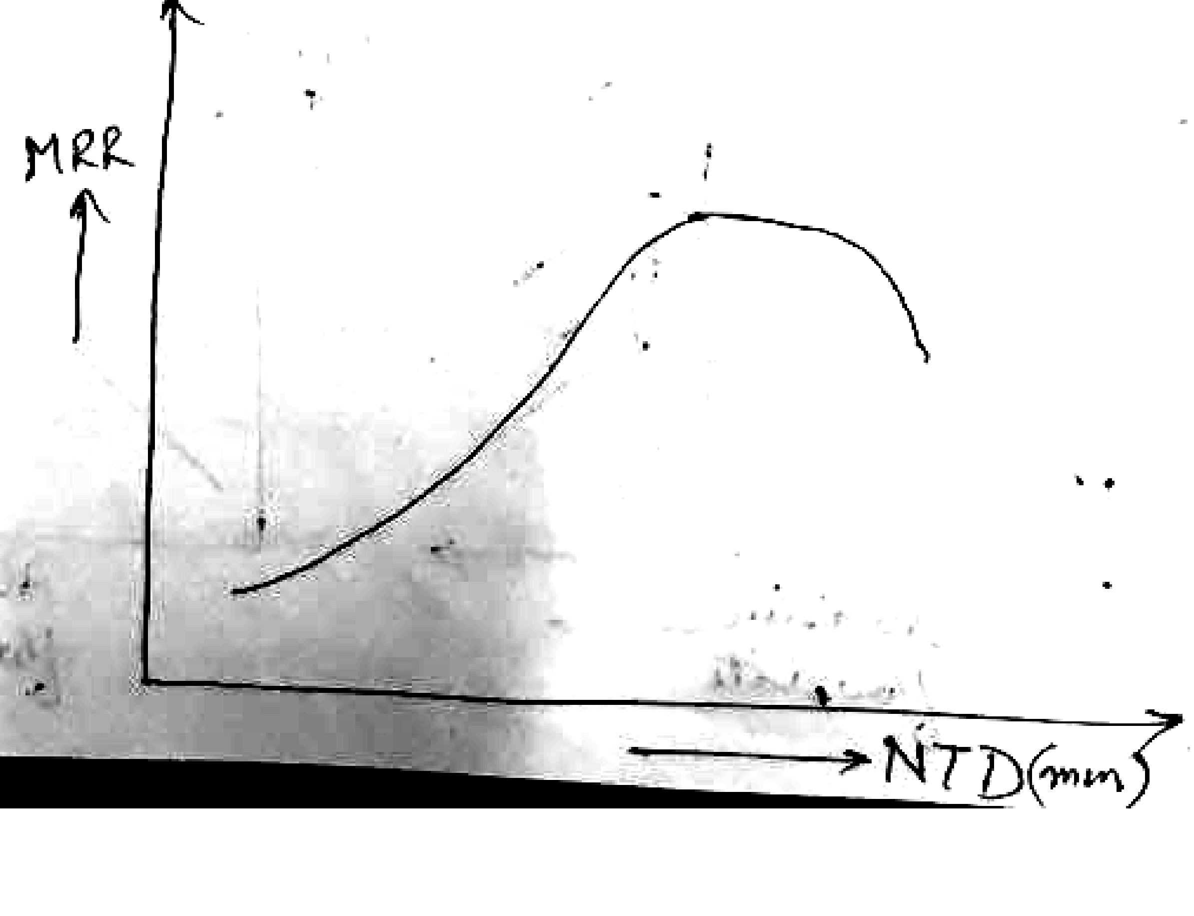
- Mechanical Processes
  - Abrasive Jet Machining (AJM)
  - Ultrasonic Machining (USM)
  - Water Jet Machining (WJM)
  - Abrasive Water Jet machining (AWJM)
- Electrochemical Processes
  - Electrochemical Machining (ECM)
  - Electrochemical Grinding (ECG)
  - Electro Jet Drilling (ETD)
- Electro-Thermal Processes
  - Electro-discharge Machining (EDM)
  - Laser Jet Machining (LJM)
  - Electron Beam Machining (EBM)
- Chemical Processes
  - Chemical Milling (CHM)
  - Photo-chemical Milling (PC[illegible]

5(i) Nozzle tip distance (NTD) or Stand-off-distance (SOD):

— It refers to the distance b/w the tip of the nozzle and the worksurface.

— MRR initially increases with increase in the distance of nozzle from the worksurface due to acc. of abrasive particles leaving the nozzle. After that limit, MRR remains const. to some extent and then decreases due to inc. in machining area for the same amount of abrasives and dec in velocity of abrasive particles stream due to drag.

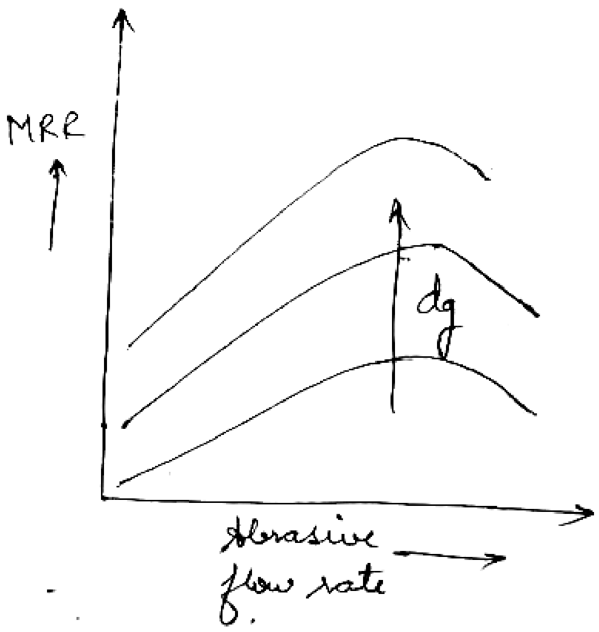
Note: The nozzle-tip distance (NTD) not only affects MRR, but also the shape and size of the cavity produced.

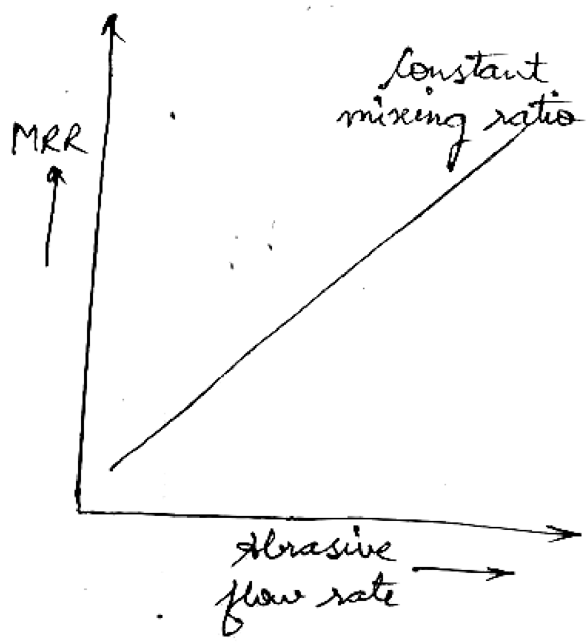


5. (ii) (iii) Abrasive flow rate and velocity:

— Inc. in flow rate of abrasives, increases MRR because more abrasive particles are available for cutting.

— However, when flow rate exceeds 14 gm/min, the abrasive velocity decreases, thereby reducing MRR. (The jet velocity is a function of the nozzle pr., nozzle design, abrasive grain size, and the mean no. of abrasives per unit volume of the carrier gas).





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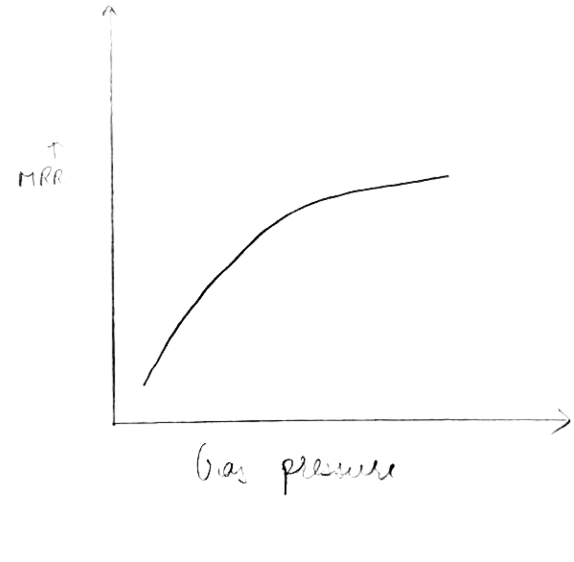


6. Effect of process parameters:

[Variables which affect the MRR, surface finish and accuracy of machined surface]

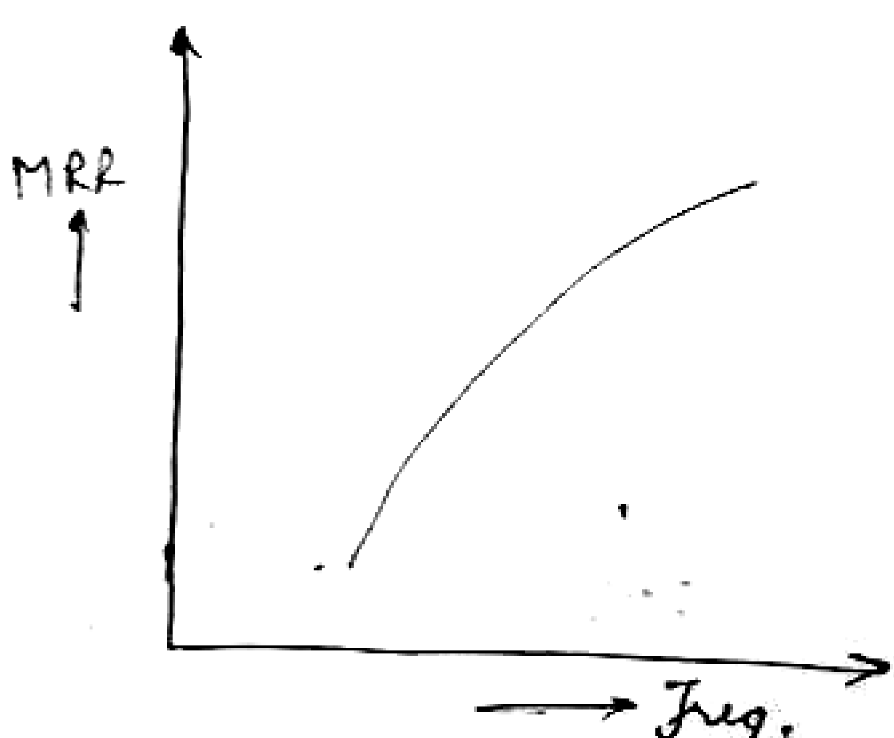
1. Effect of amplitude and frequency:

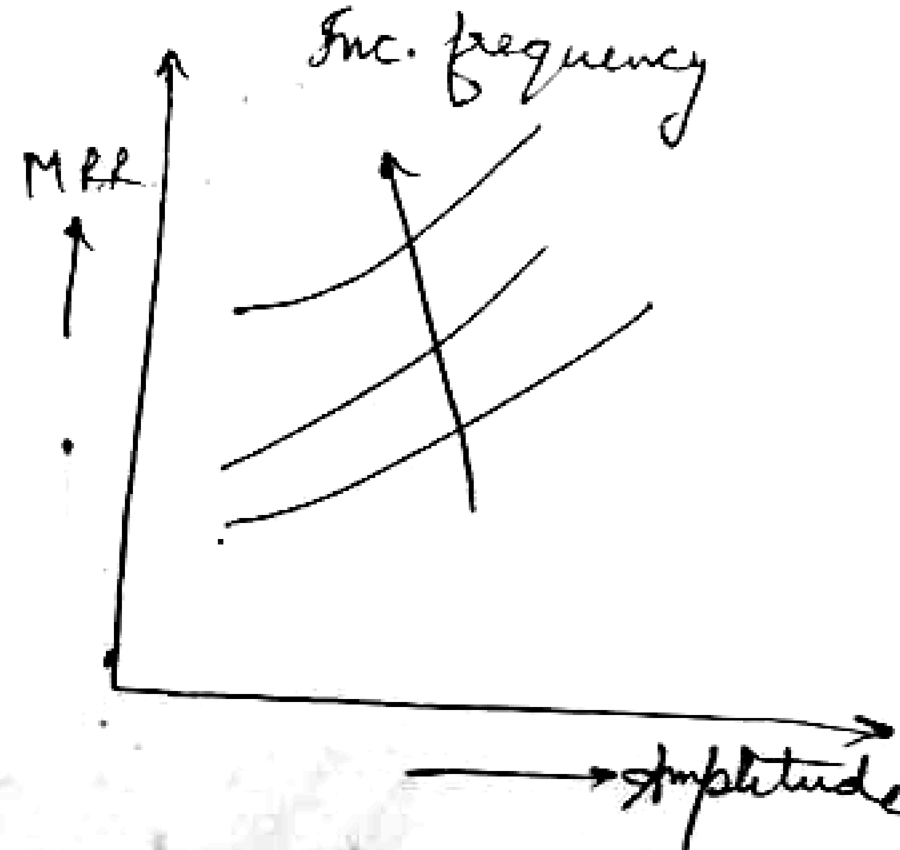
The MRR or cutting rate increases with increase in both amplitude and vibration of the tool. The amplitude and freq. of vibration determines the velocity of the abrasive particles at the interface b/w tool and w/p. At

↑ amplitudes ⇒ K.E. ↑ ⇒ ↑ mech. chipping action ⇒ ↑ MRR

But,

↑ amplitude → ↑ surface roughness (minimal effect)





2. Slurry (Abrasive – water mixture):

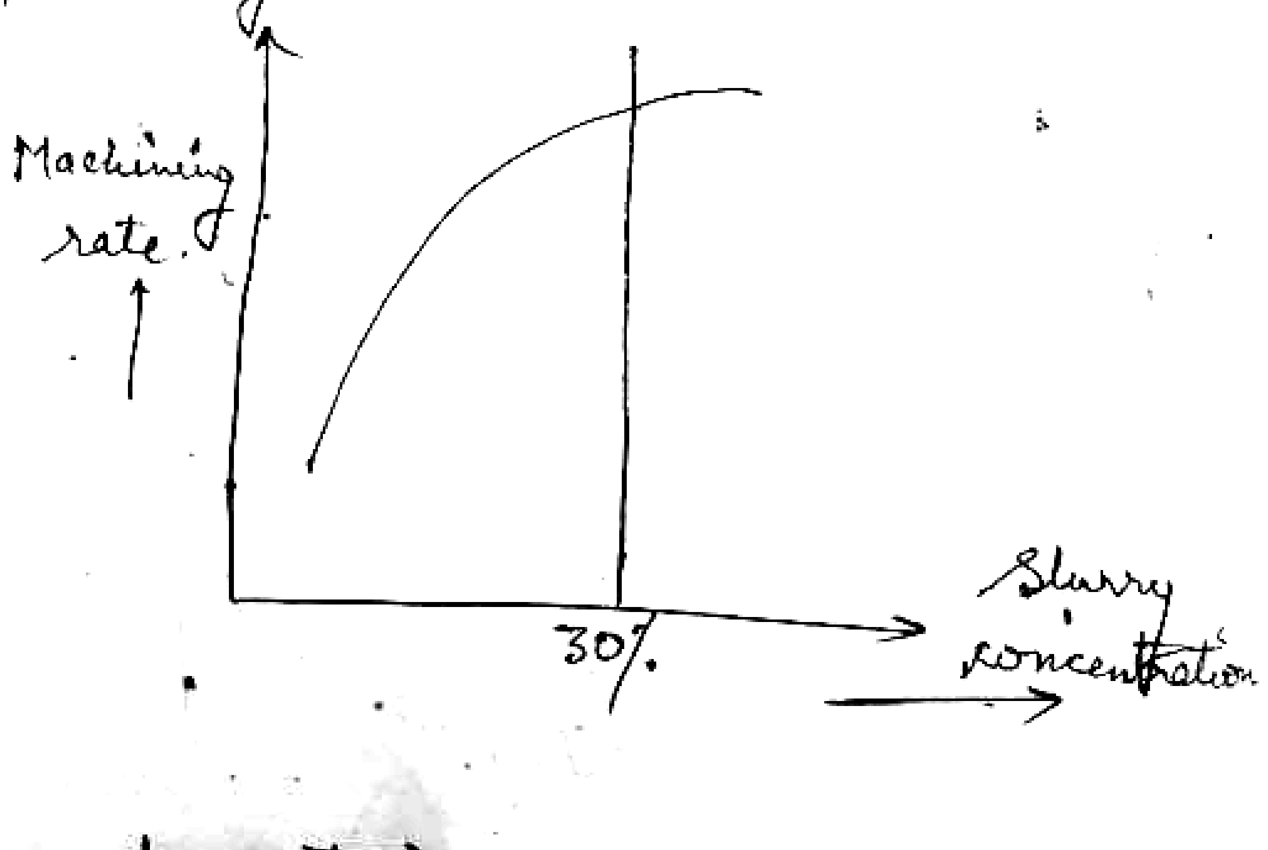
— Improved flow of slurry results in an enhanced machining rate.

— Volumetric η of about 30–35% of abrasive is recommended.

— The actual conc. ~~about~~ should, ~~therefore~~ be checked at certain time intervals.

↑ Slurry conc ⟹ ↑ MRR

— Machining rate reaches to a optimum value with 30% slurry conc.

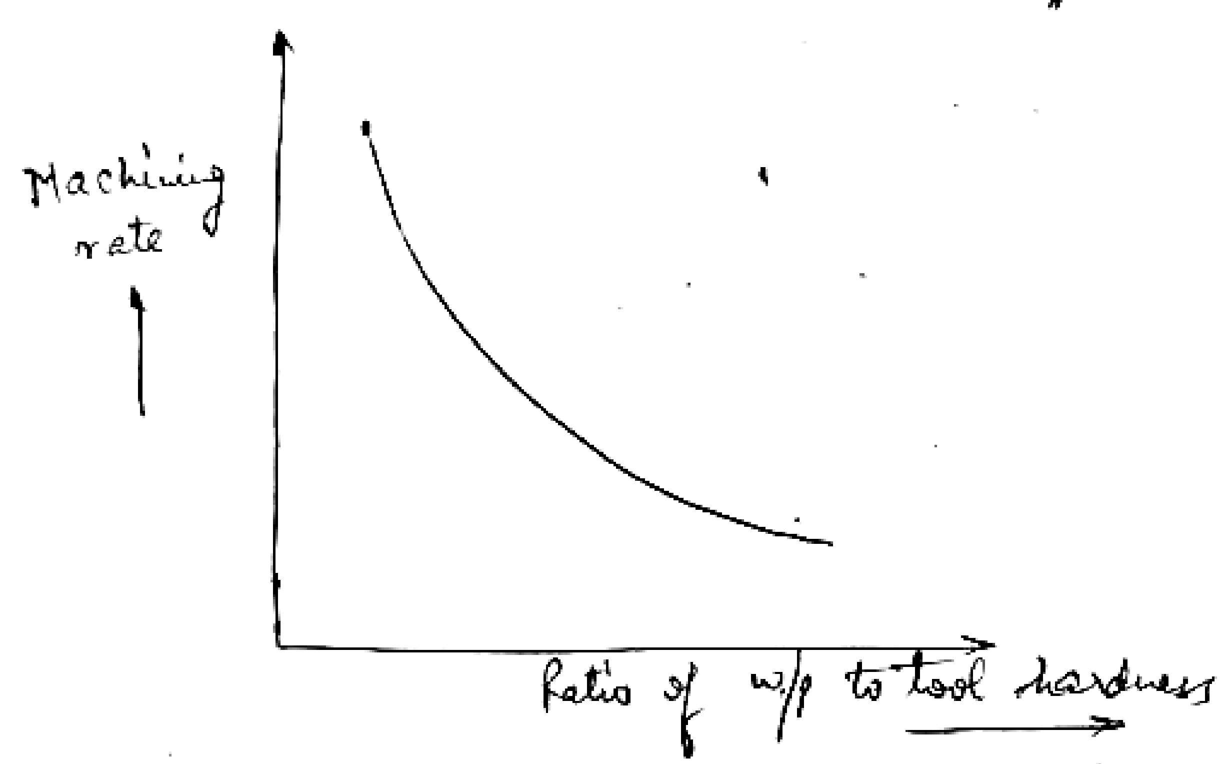


3. Tool and work material:

— Tool should not fail or wear out quickly, as it has to withstand the vibrations.

— The harder the tool, the faster its wear rate will be, therefore unfavourable MRR and surface finish on w/p.

— Tough malleable materials such as alloy steels and stainless steel give satisfactory results.



4. Type of abrasive:

— Abrasive used should be harder than the w/p material being machined, else the life time of the abrasive will be substantially shortened resulting in poor surface finish during subsequent machining.

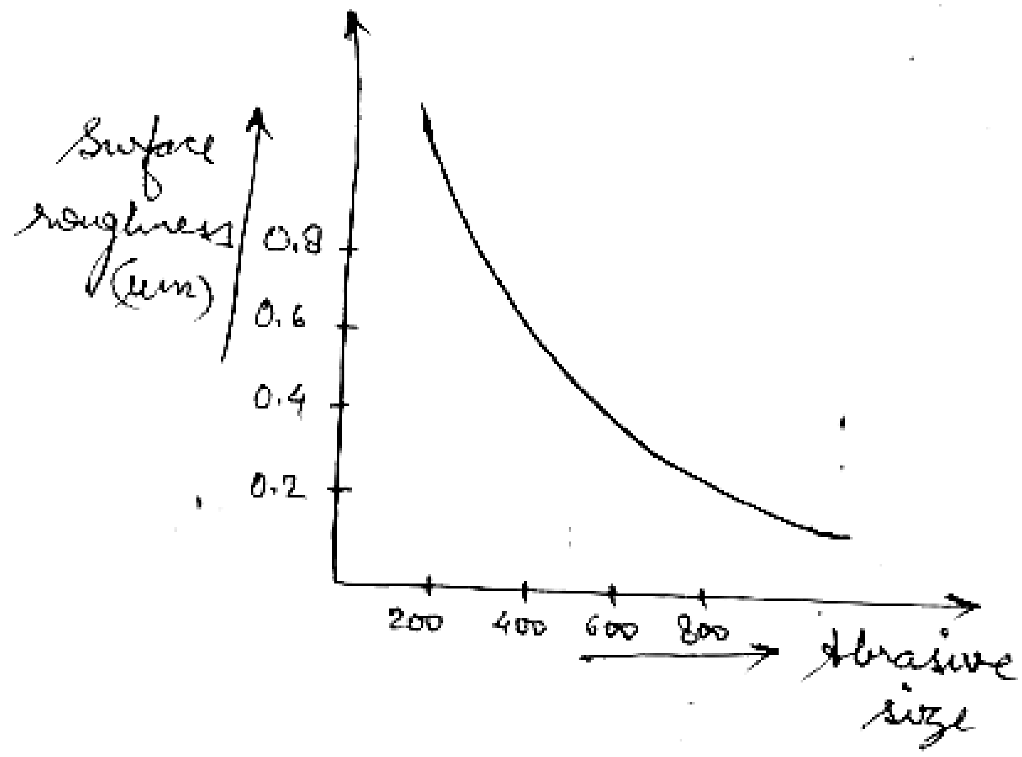
— Boron Carbides is used for high metal removal rates and also for hard w/p materials like tungsten carbide, tool steel and precious stones.

— Silicon Carbide is best suited and finds max. appl's in USM

5. Abrasive size:

— The size of the abrasive particle varies b/w 240–800 grit. Coarse grades are suitable for high metal removal rates, but result in rough surface finish.

— Finer grades, say 750–800 grit are used for fine surface finish, but the MRR decreases.



— The cutting rate increases with increase in grain size however there is a limit to the effect of grain size on the rate as a very coarse abrasive powder may even cause a fall in cutting rate.

6. Effect of applied static load (feed force):

— In practice, initially with inc. in static load on the tool, the depth of penetration of the abrasive particles on the work surface is more, leading to increased MRR. However, there is a limit to the applied static load, and beyond this limit, the depth of penetration is found to decrease leading to low MRR.