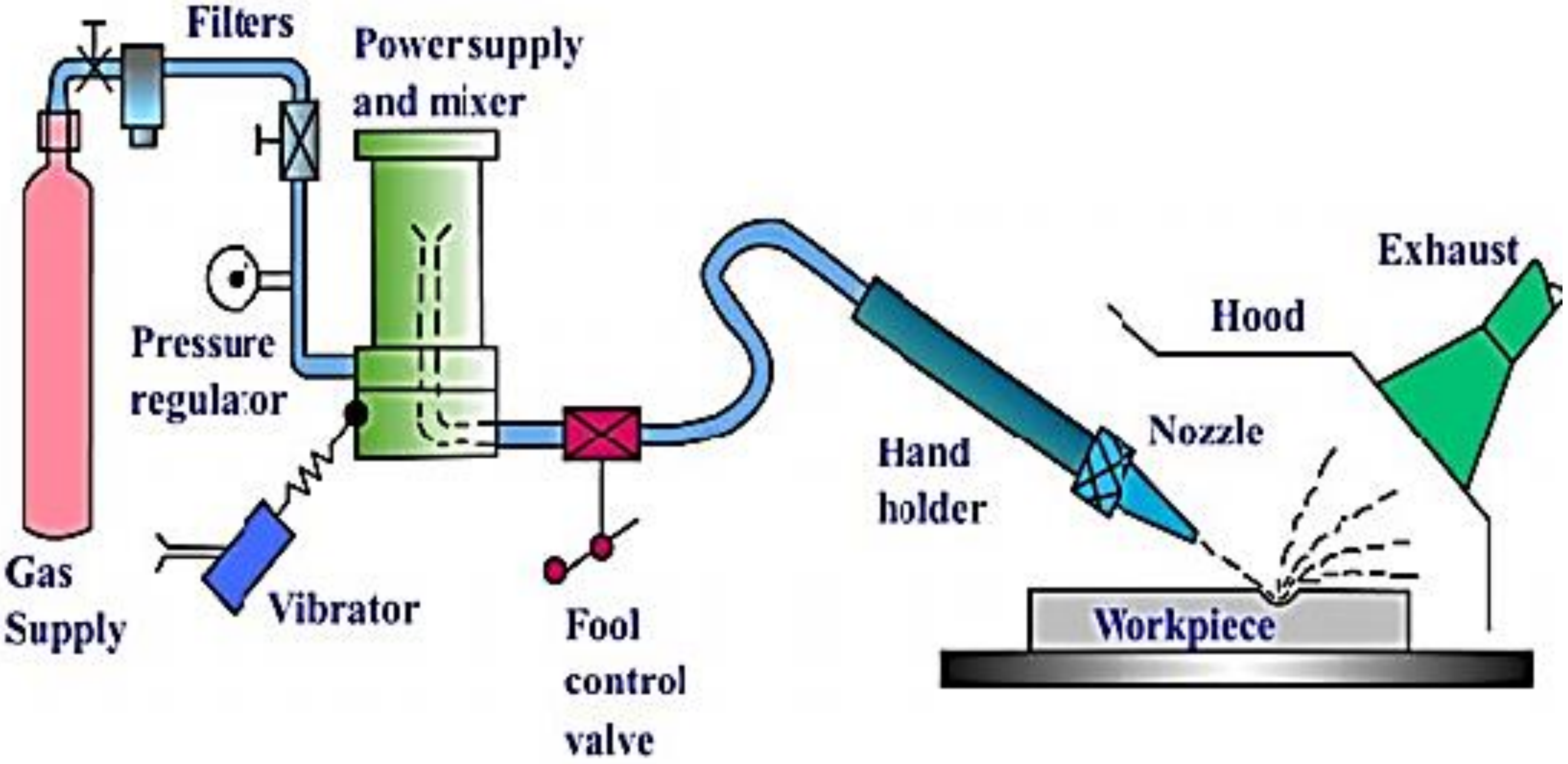
ABRASIVE JET MACHINING

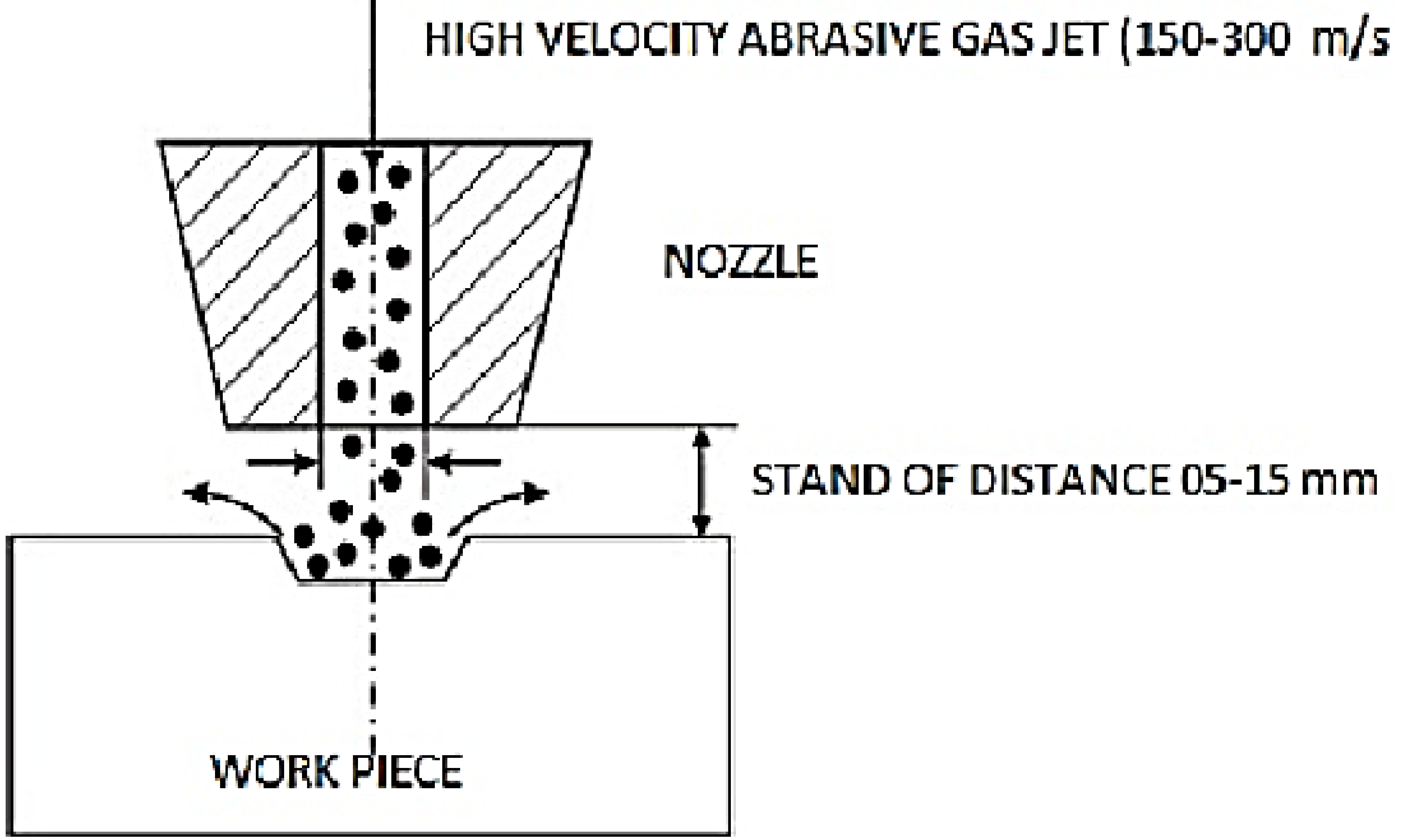

Filters
Power supply
and mixer
Pressure
regulator
Gas
Supply
Vibrator
Fool
control
valve
Hand
holder
Nozzle
Hood
Exhaust
Workpiece

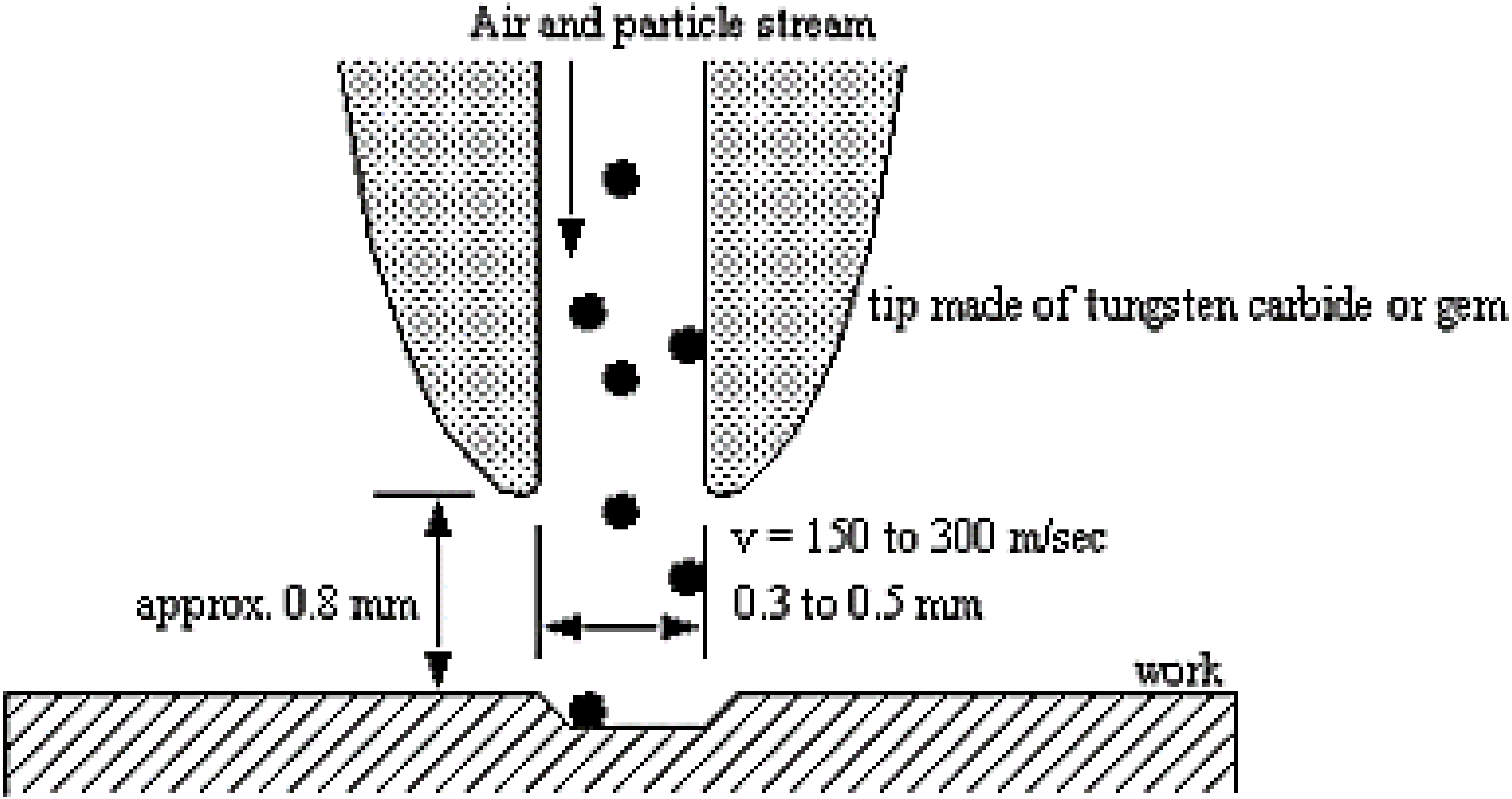
- ✓ In Abrasive Jet Machining (AJM), abrasive particles are made to impinge on the work material at a high velocity. The jet of abrasive particles is carried by carrier gas or air.

- ✓ High velocity stream of abrasive is generated by converting the pressure energy of the carrier gas or air to its kinetic energy and hence high velocity jet.

- ✓ Nozzle directs the abrasive jet in a controlled manner onto the work material, so that the distance between the nozzle and the work piece and the impingement angle can be set desirably.

- ✓ High velocity abrasive particles remove the material by micro-cutting action as well as brittle fracture of the work material.


HIGH VELOCITY ABRASIVE GAS JET (150-300 m/s
NOZZLE
STAND OF DISTANCE 05-15 mm
WORK PIECE


Air and particle stream
tip made of tungsten carbide or gem
v = 150 to 300 m/sec
0.3 to 0.5 mm
approx. 0.8 mm
work

Physics of the Process:

- Fine particles (0.025mm) are accelerated in a gas stream
- The particle are directed towards the focus of machining
- As the particles impact the surface, it causes a micro fracture, and gas carries fractured particles away
- Brittle and fragile work better

Process:-

- In AJM, air is compressed in an air compressor and compressed air at a pressure of around 5 bar is used as the carrier gas.
- Gases like CO_2, N_2 can also use. Generally oxygen is not used as a carrier gas.

- Carrier gas is first passed through a pressure regulator to obtain the desired working pressure. Gas is then passed through an air dryer to remove any residual water vapour. To remove any oil vapour or particulate contaminant the same is passed through a series of filters.

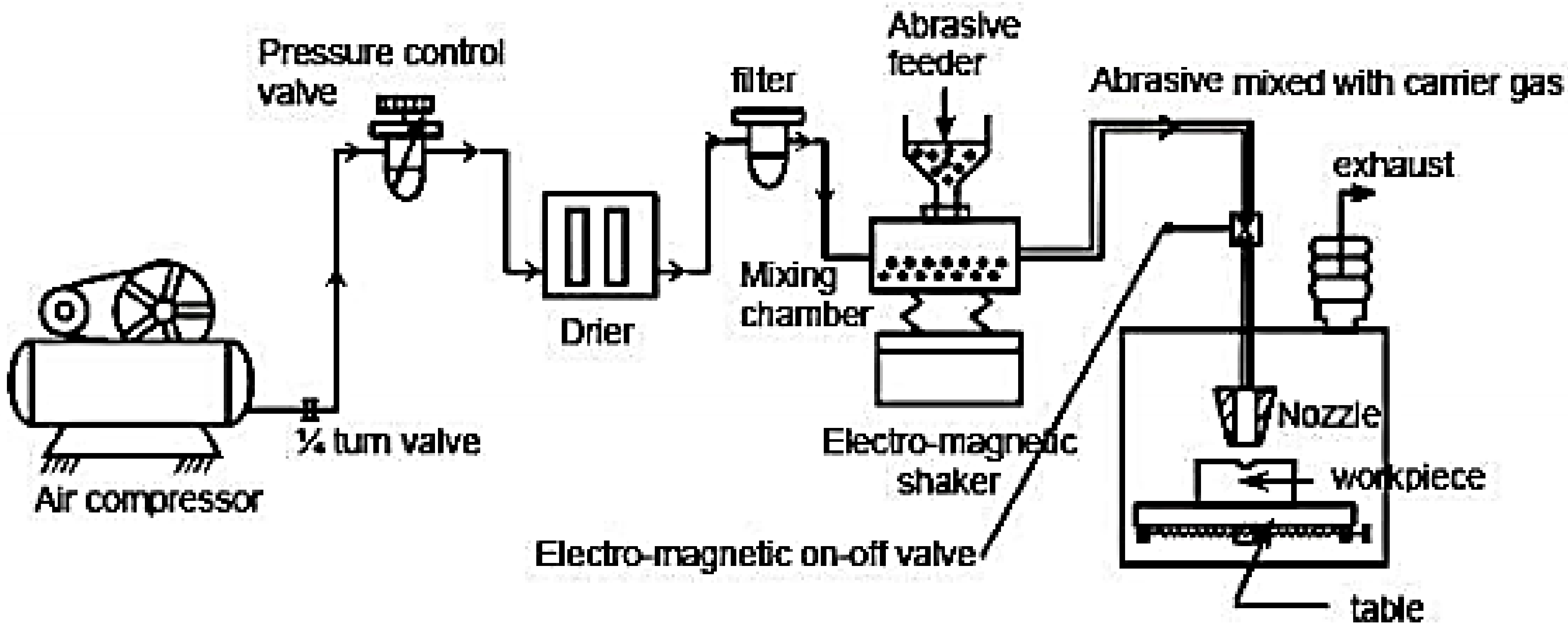
- Then the carrier gas enters a closed chamber known as the mixing chamber.

- Abrasive particles enter the chamber from a hopper through a metallic sieve.

- Sieve is constantly vibrated by an electromagnetic shaker.

The abrasive particles are then carried by the carrier gas to the machining chamber via an electro-magnetic on-off valve. The machining is carried out as high velocity (200 m/s) abrasive particles are issued from the nozzle onto a work piece traversing under the jet.

Equipment:


Pressure control valve
filter
Abrasive feeder
Abrasive mixed with carrier gas
exhaust
Drier
Mixing chamber
Air compressor
¼ turn valve
Electro-magnetic shaker
Nozzle
workpiece
Electro-magnetic on-off valve
table

Abrasive jet Machining consists of

1. Gas propulsion system
2. Abrasive feeder
3. Machining Chamber
4. AJM Nozzle
5. Abrasives

Gas Propulsion System

- 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.
- 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.

Abrasive Feeder

- Required quantity of abrasive particles is supplied by abrasive feeder. Filleted propellant is fed into the mixing chamber where in abrasive particles are fed through a sieve.
- Sieve is made to vibrate at 50-60 Hz and mixing ratio is controlled by the amplitude of vibration of sieve.
- Particles are propelled by carrier gas to a mixing chamber. Air abrasive mixture moves further to nozzle.
- Nozzle imparts high velocity to mixture which is directed at work piece surface.

Machining chamber

- ✓ It is well closed so that concentration of abrasive particles around the working chamber does not reach to the harmful limits.

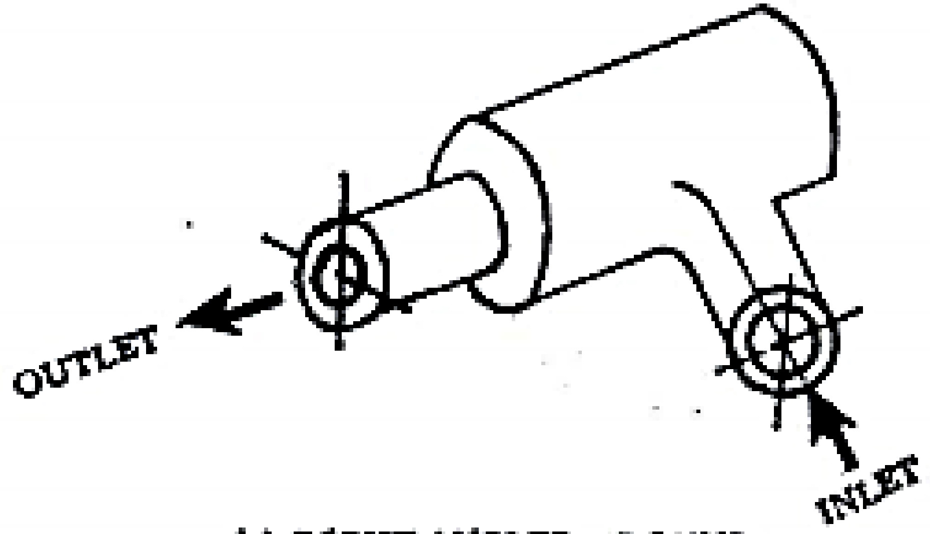
- ✓ Machining chamber is equipped with vacuum dust collector.

- ✓ Special consideration should be given to dust collection system if the toxic material (like *beryllium*) are being machined.

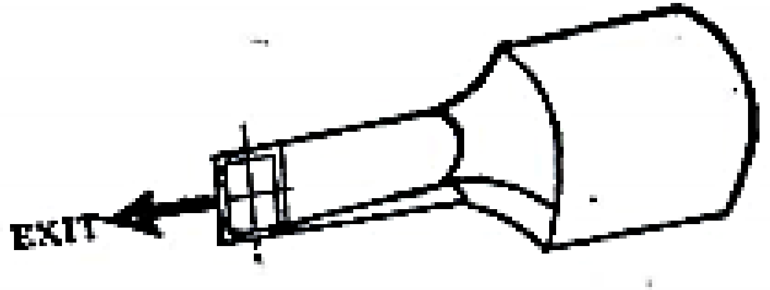
AJM nozzle

- 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.
- 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.

- Nozzles
  - Round-shaped slots
    - Right angled nozzle
    - Straight edge nozzle
  - Rectangular-shaped slots
    - Rectangular nozzle
    - Straight edge nozzle



(a) RIGHT-ANGLED, ROUND SHAPED NOZZLE



(b) STRAIGHT EDGE RECTANGULAR SHAPED NOZZLE

NOZZLE MATERIAL	ROUND SHAPE NOZZLE DIAMETER, MM	RECTANGULAR SHAPE SLOT, DIMENSION, MM	LIFE OF NOZZLE, HOURS
Tungsten 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

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 1.27mm	Gives matte finish
Dolomite	200 mesh	Etching and polishing
Sodium bi carbonate	27 micros	Cleaning, deburring and cutting of soft material Light finishing below 50^0C

Process parameters

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

Process criteria are generally influenced by the process parameters:

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 15mm.
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 0.25mm ± 0.12mm
3. Surface finish -0.25 micron to 1.25 micron
4. Sharp radius up to 0.2mm is possible
5. Steel up to 1.5mm ,Glass up to 6.3mm is possible to cut
6. Machining of thin sectioned hard and brittle materials is possible.

Applications

1. This is used for abrading and frosting glass more economically as compared to etching or grinding
2. Cleaning of metallic smears on ceramics, oxides on metals, resistive coating etc.
3. AJM is useful in manufacture of electronic devices , drilling of glass wafers, de burring of plastics, making of nylon and Teflon parts permanent marking on rubber stencils, cutting titanium foils
4. Deflashing small castings, engraving registration numbers on toughened glass used for car windows
5. Used for cutting thin fragile components like germanium, silicon etc.

6. Register treaming can be done very easily and micro module fabrication for electrical contact , semiconductor processing can also be done effectively.

7. Used for drilling , cutting , deburring etching and polishing of hard and brittle materials.

8. Most suitable for machining brittle and heat sensitive materials like glass, quartz, sapphire , mica , ceramics germanium , silicon and gallium.

9. It is also good method for deburring small hole like in hypodermic needles and for small milled slots in hard metallic components.

Advantages

1. High surface finish can be obtained depending upon the grain sizes

Particle size (in microns)	Surface roughness (in microns)
10	0.152 to 0.203
25 to 27	0.355 to 0.675
50	0.965 to 1.27

2. Depth of damage is low (around2.5 microns)
3. It provides cool cutting action, so it can machine delicate and heat sensitive material

4.Process is free from chatter and vibration as there is no contact between the tool and work piece

5.Capital cost is low and it is easy to operate and maintain AJM.

6.Thin sections of hard brittle materials like germanium, mica, silicon, glass and ceramics can be machined.

7.It has the capability of cutting holes of intricate shape in hard materials.

Disadvantages /Limitations

1. Limited capacity due to low **MRR. MRR** for glass is 40 gm/minute
2. Abrasives may get embedded in the work surface, especially while machining soft material like elastomers or soft plastics.
3. The accuracy of cutting is hampered by tapering of hole due to unavoidable flaring of abrasive jet.
4. Stray cutting is difficult to avoid
5. A dust collection system is a basic requirement to prevent atmospheric pollution and health hazards.
6. Nozzle life is limited (300 hours)
7. Abrasive powders cannot be reused as the sharp edges are worn and smaller particles can clog the nozzle.
8. Short stand off distances when used for cutting , damages the nozzle.

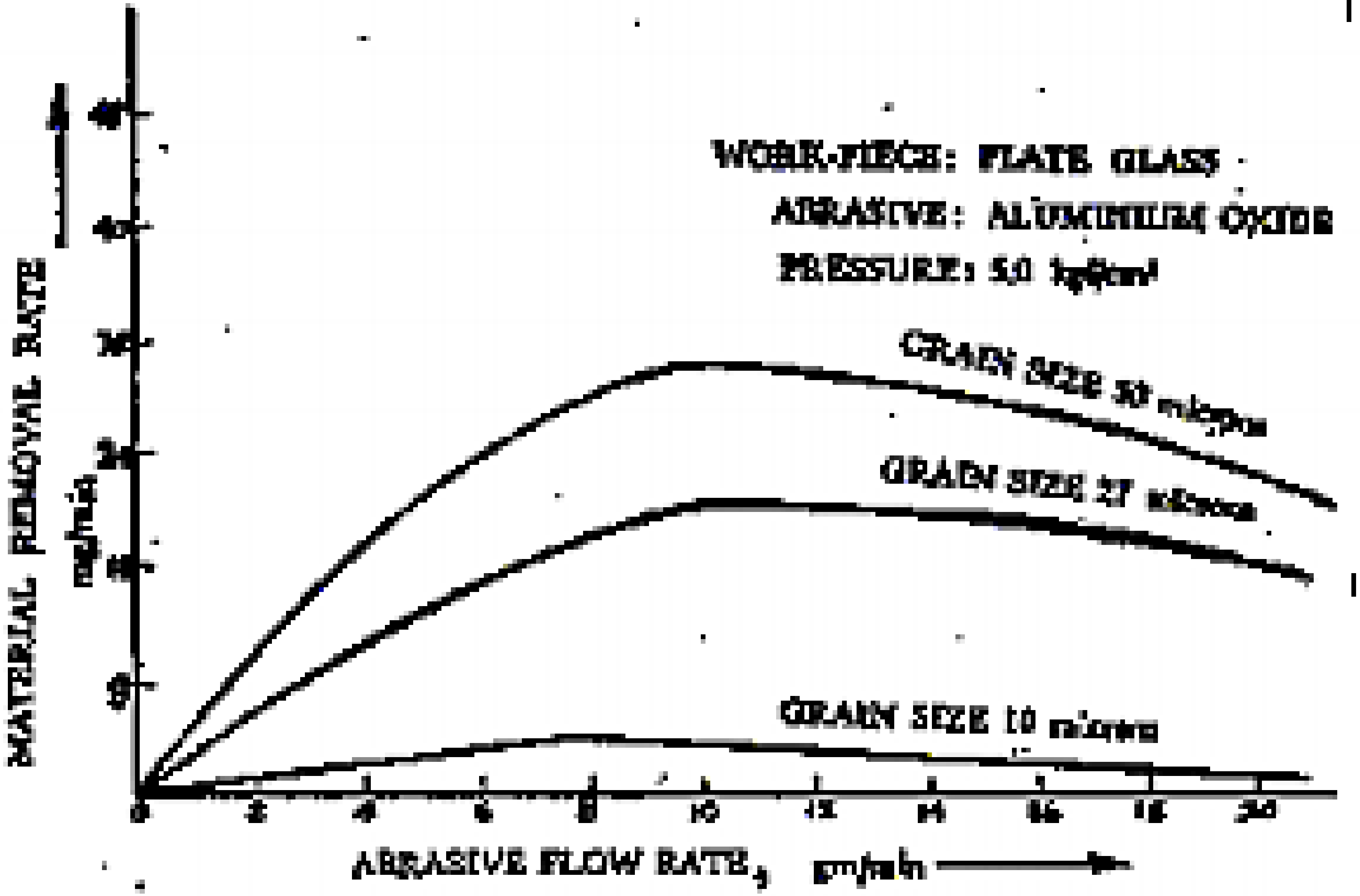
Machining characteristics

Following are the AJM process criteria

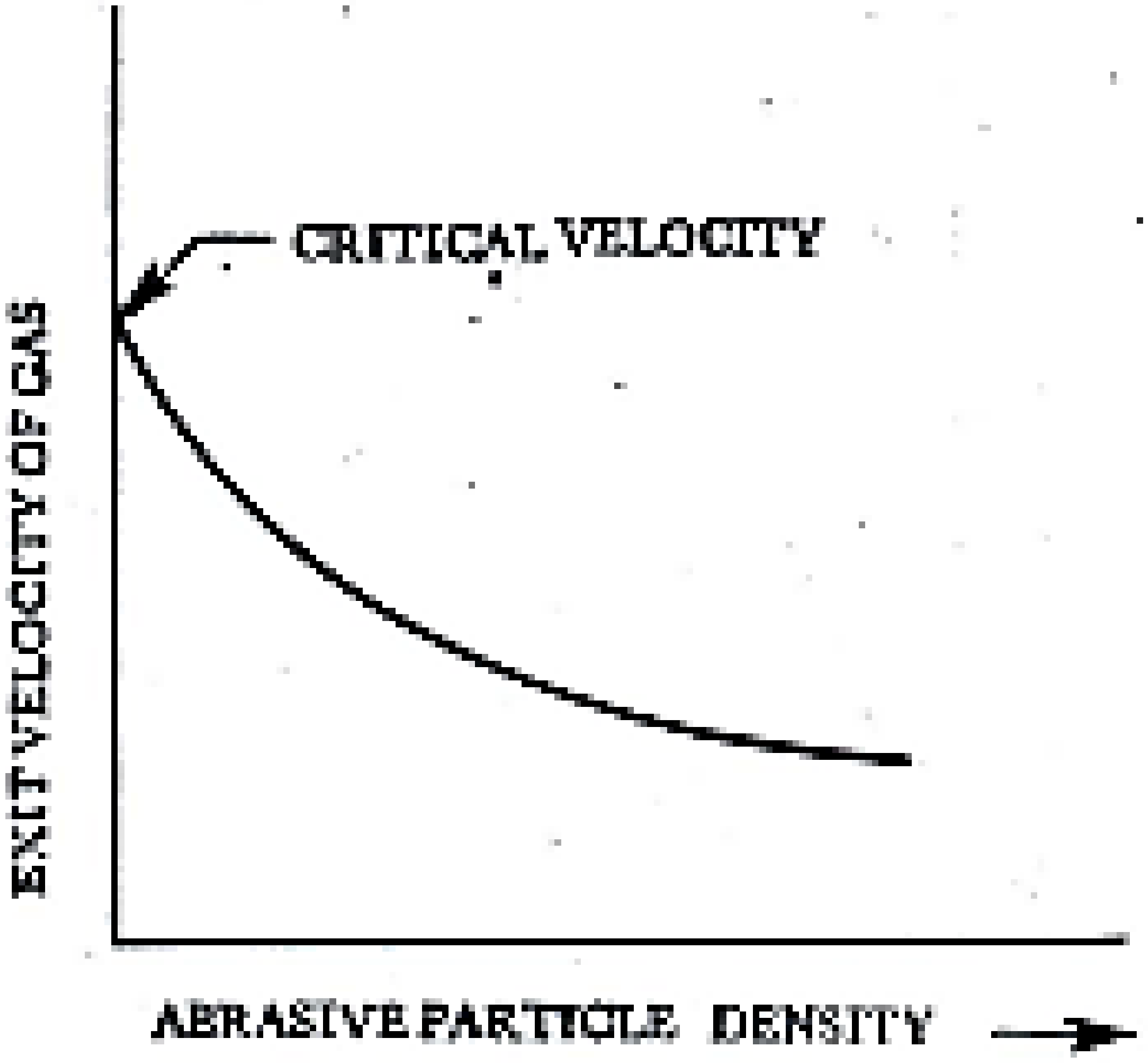
1. Material removal rate
2. Geometry and surface finish of work piece
3. wear rate of the nozzle

Process criteria are generally influenced by the process parameters

Effect of abrasive flow rate and grain size on MRR

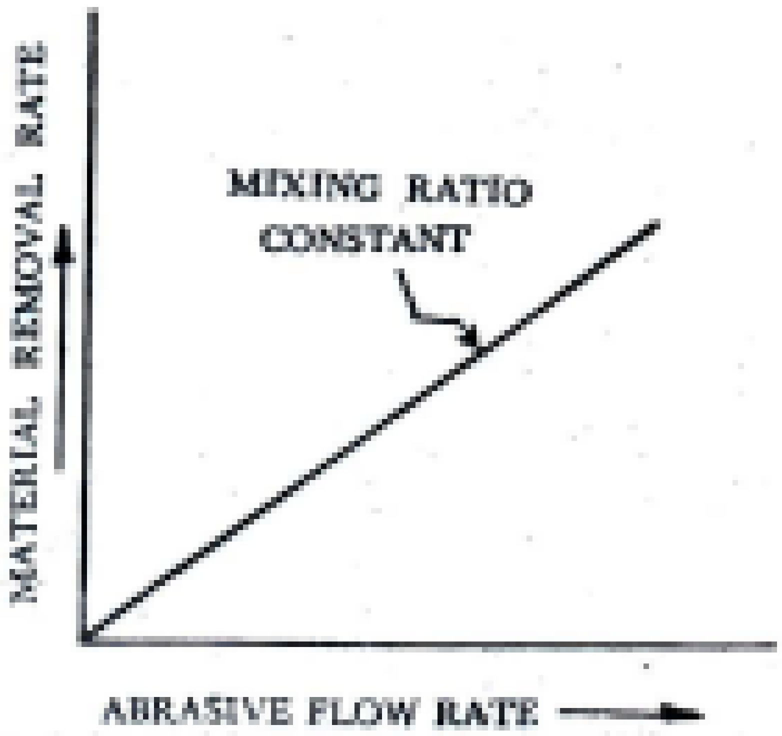


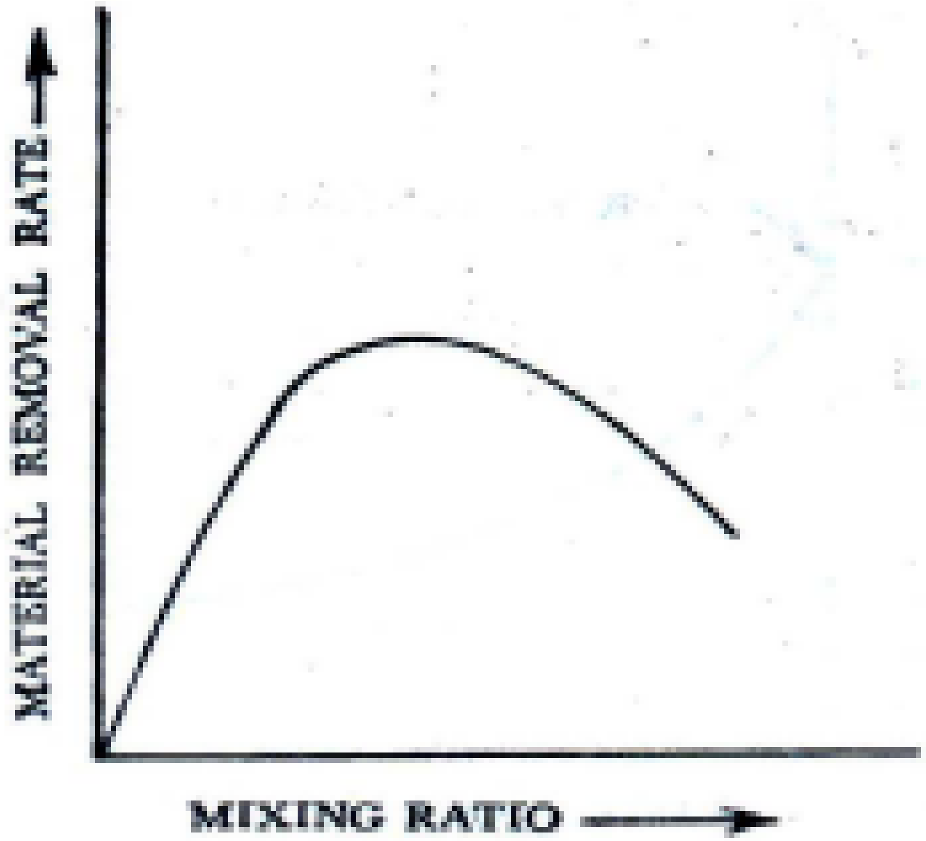
Effect of exit gas velocity and abrasive particle density



Effect of Mixing ratio on MRR

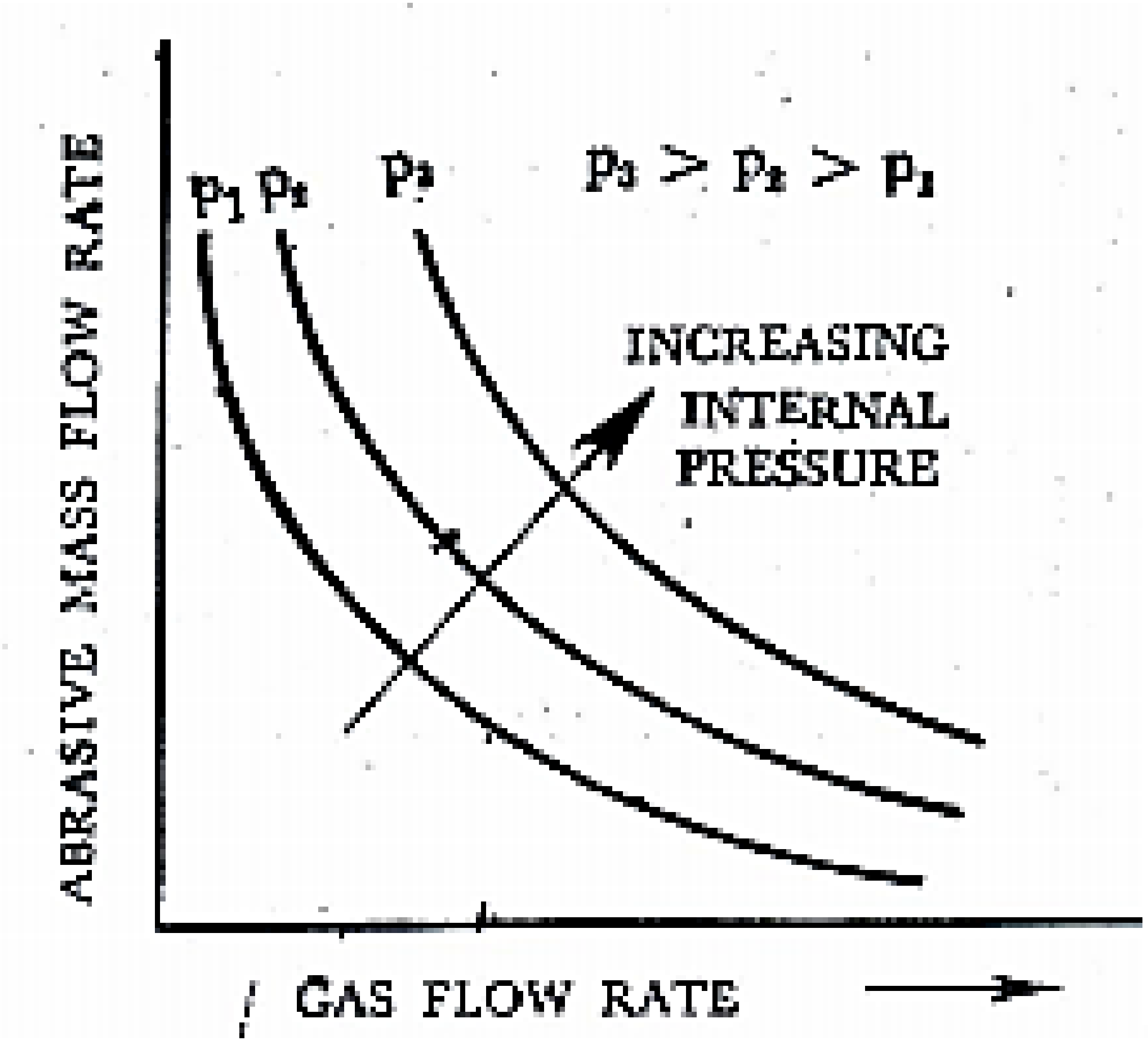
$$\text{Mixing ratio} = \frac{\text{Volume flow rate of carrier gas}}{\text{Volume flow rate of carrier gas}}$$

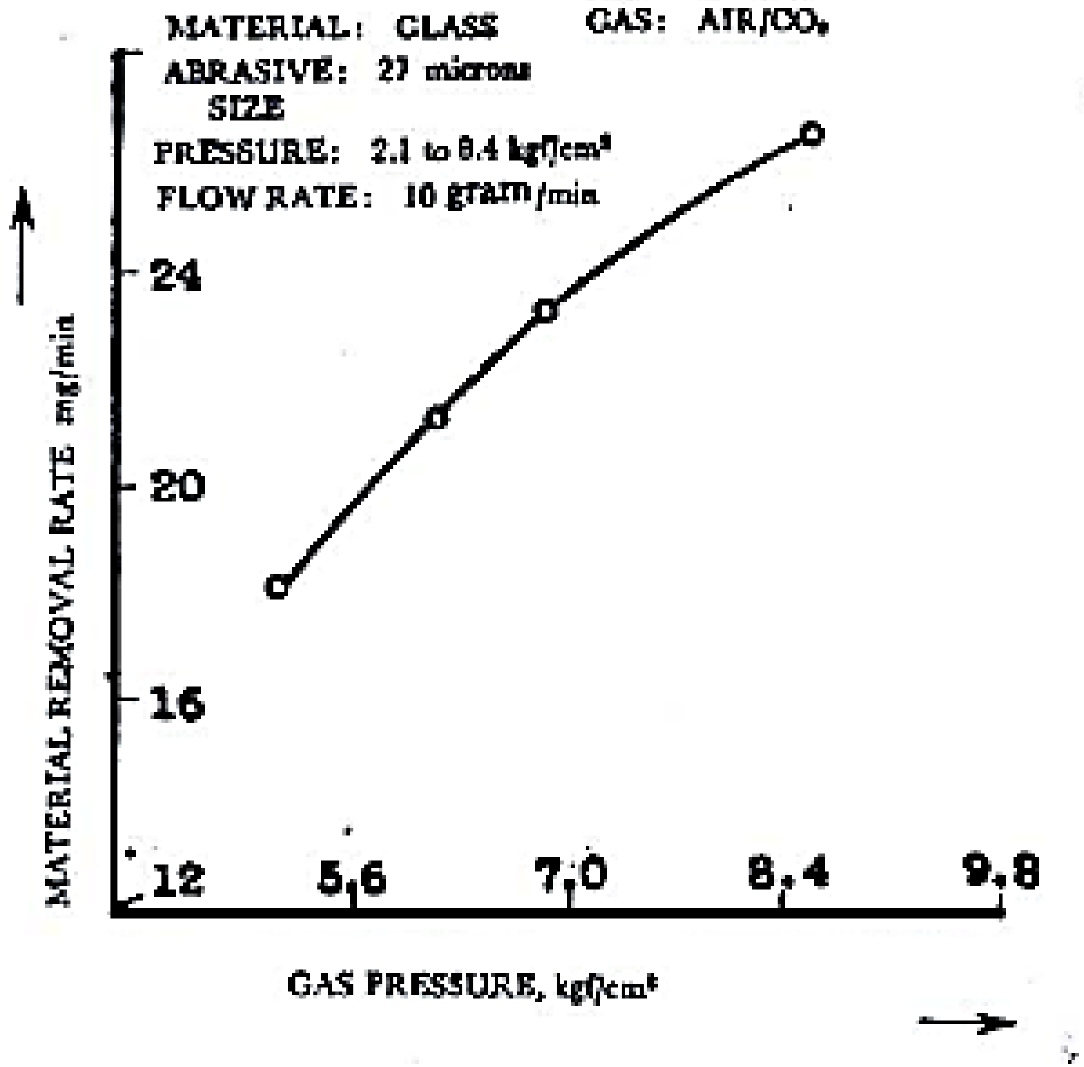




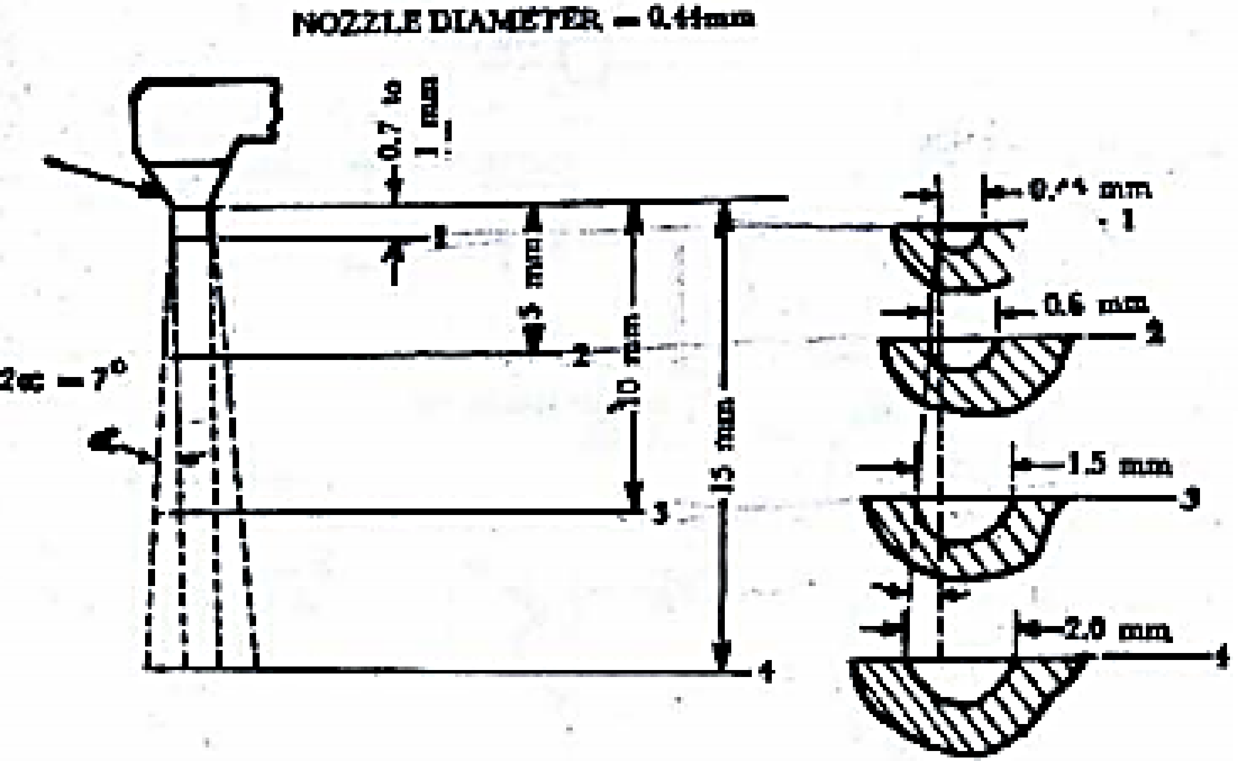
$$\alpha = \frac{\text{Mass flow rate of carrier gas}}{\text{Mass flow rate of carrier gas and abrasive}} = \frac{m_a}{m_{a+g}}$$

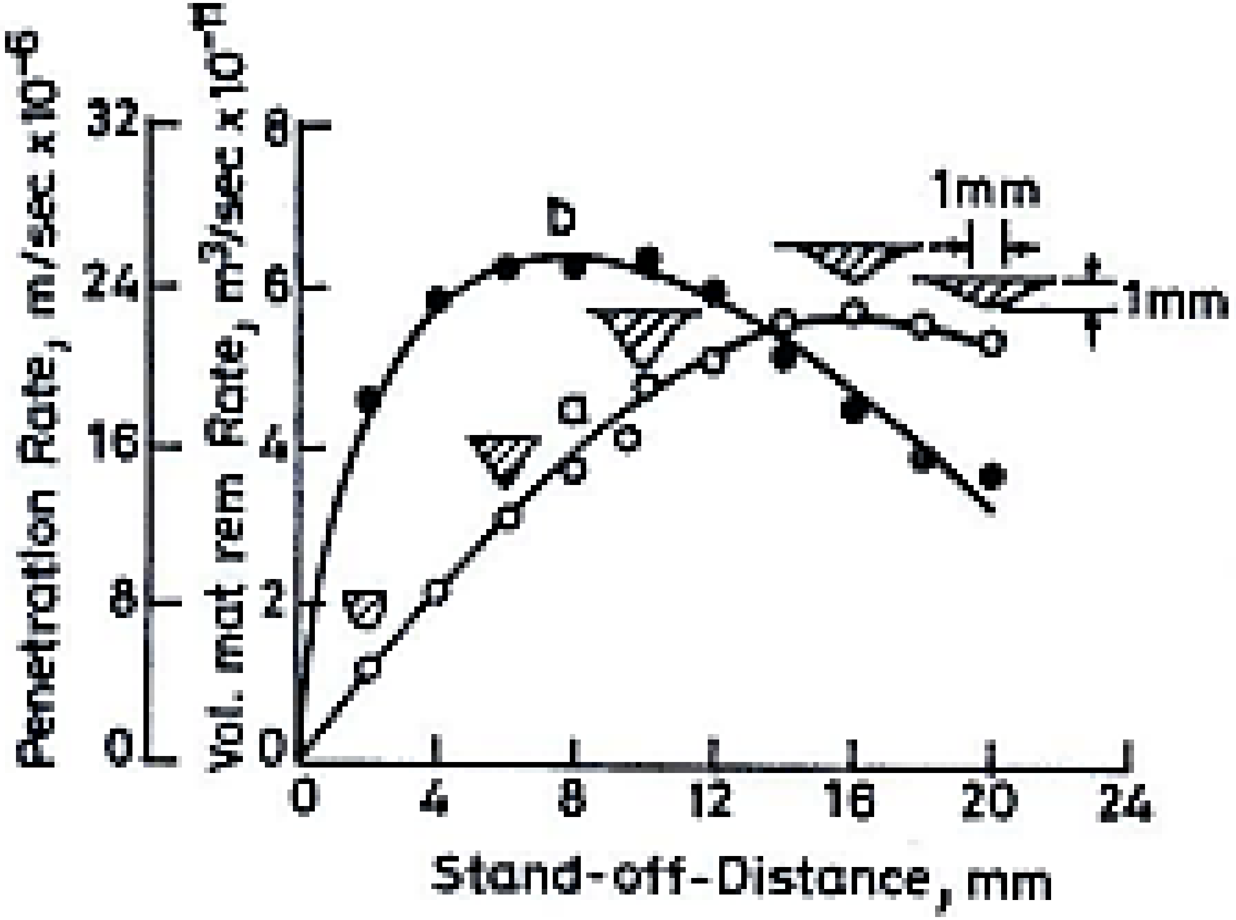
Effect of Nozzle pressure on MRR





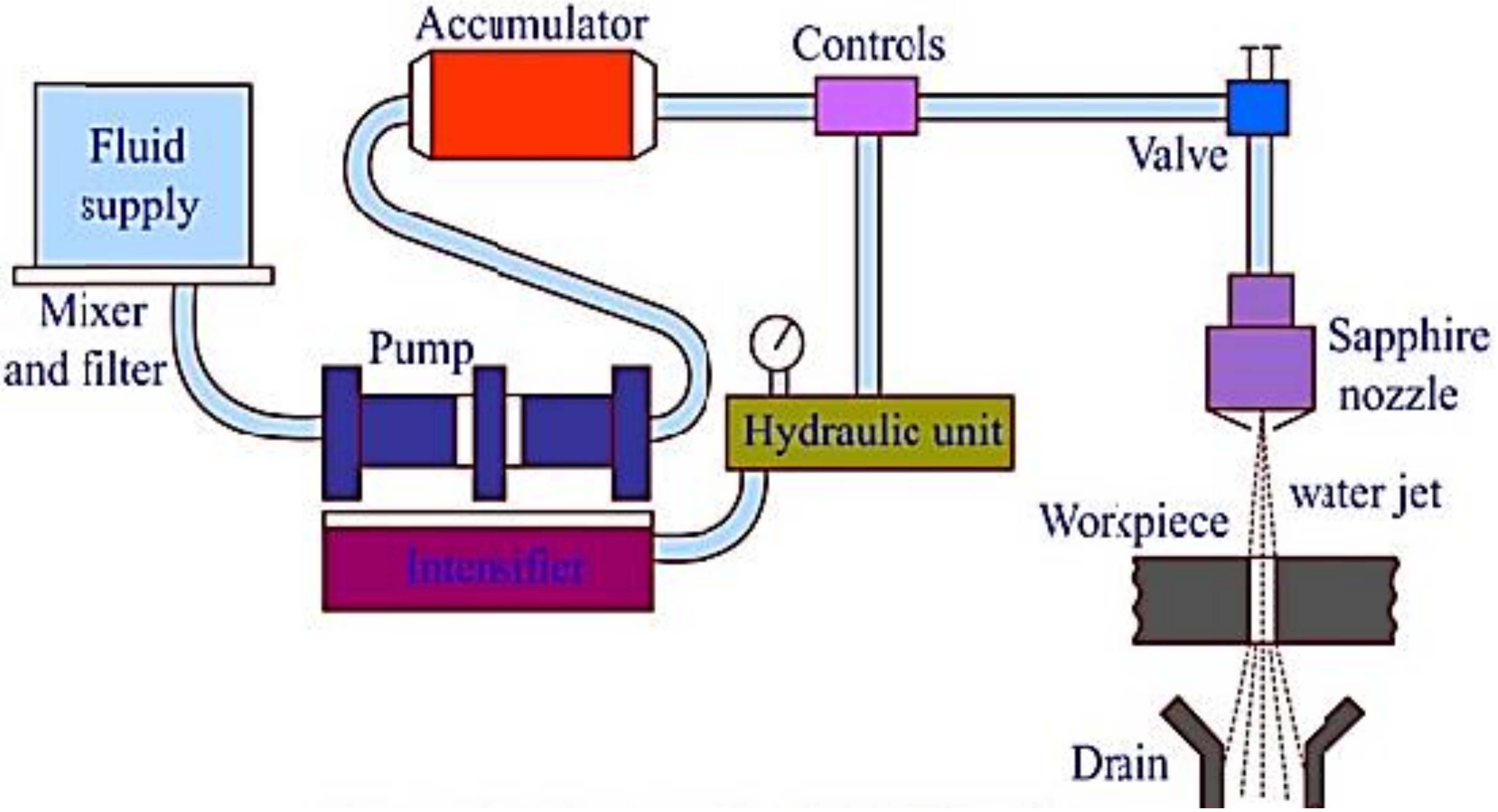
Stand off distance



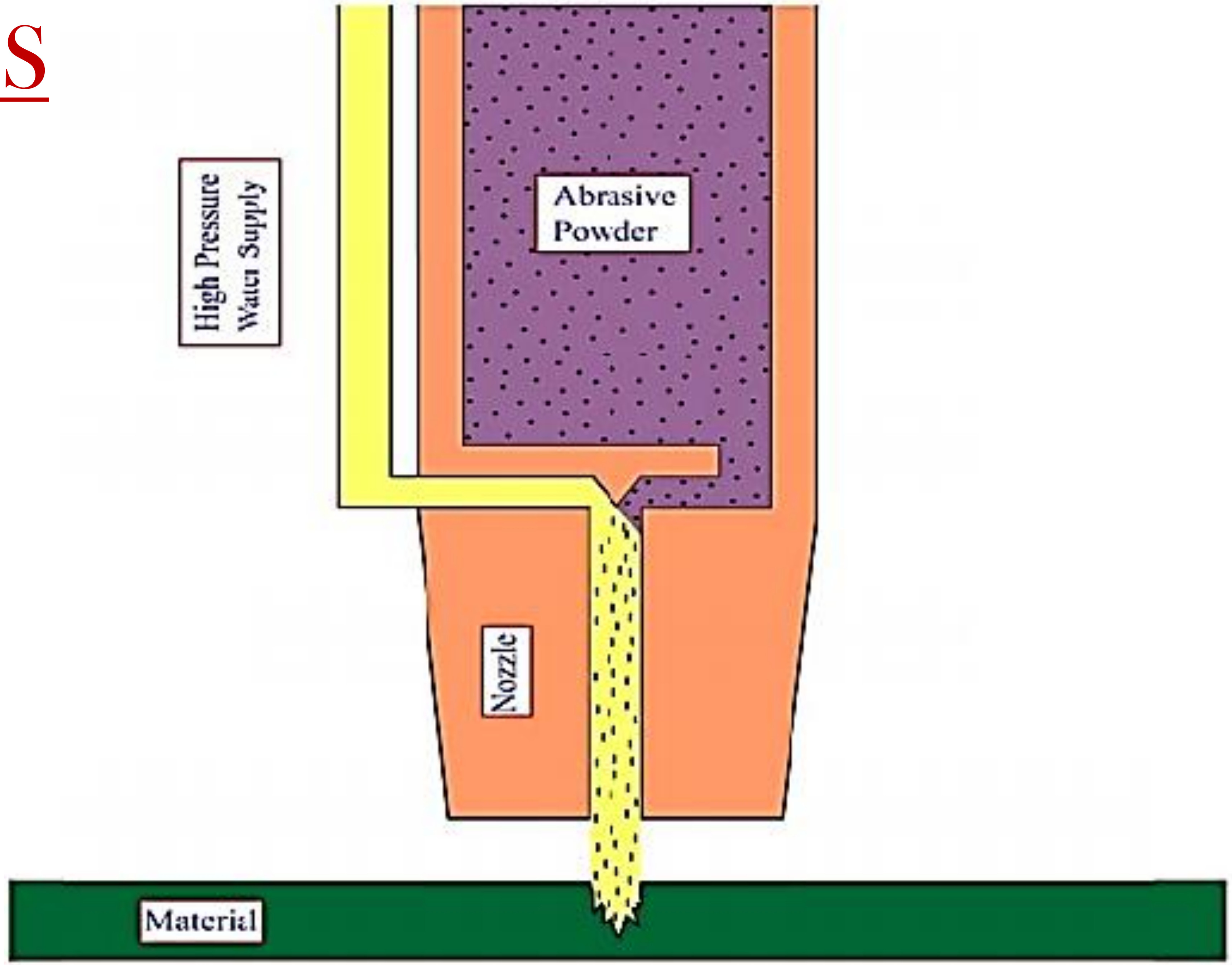


ABRASIVE WATER JET MACHINING (AWJM)

ABRASIVE WATER JET MACHINE – EQUIPMENT DETAILS



PROCESS



High Pressure
Water Supply
Abrasive
Powder
Nozzle
Material

- Abrasive Water Jet Machining (AWJM) is non-traditional or non- conventional machining process. `

- In these processes (WJM and AJWM), the mechanical energy of water and abrasive phases are used to achieve material removal or machining.

- Fine, high pressure(1500- 4000 MN/cm^2), high velocity (twice the speed of sound)of water jet is bombarded onto the work surface.

- High velocity water jet is directed at a target in such a way that the velocity is reduced to zero on striking the workpiece.

- K.E. of jet is converted into the high pressure.
- Erosion if pressure > strength of material.

Mechanism

- Given amount of energy is concentrated onto a very small point to cause the material removal.

- On striking the K.E is converted into the pressure energy (stagnation pressure).

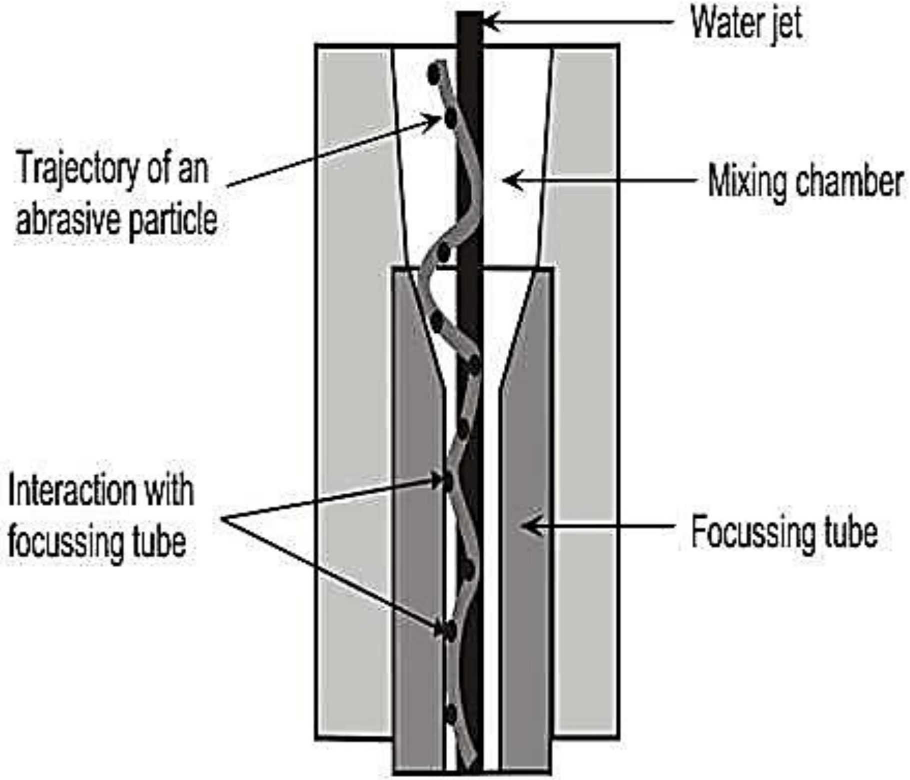
- Mechanism is erosion – localized compressive failure which occurs when the local fluid pressure exceeds the strength of the target material.
- Ductile – erosion due to shearing action.

Pump

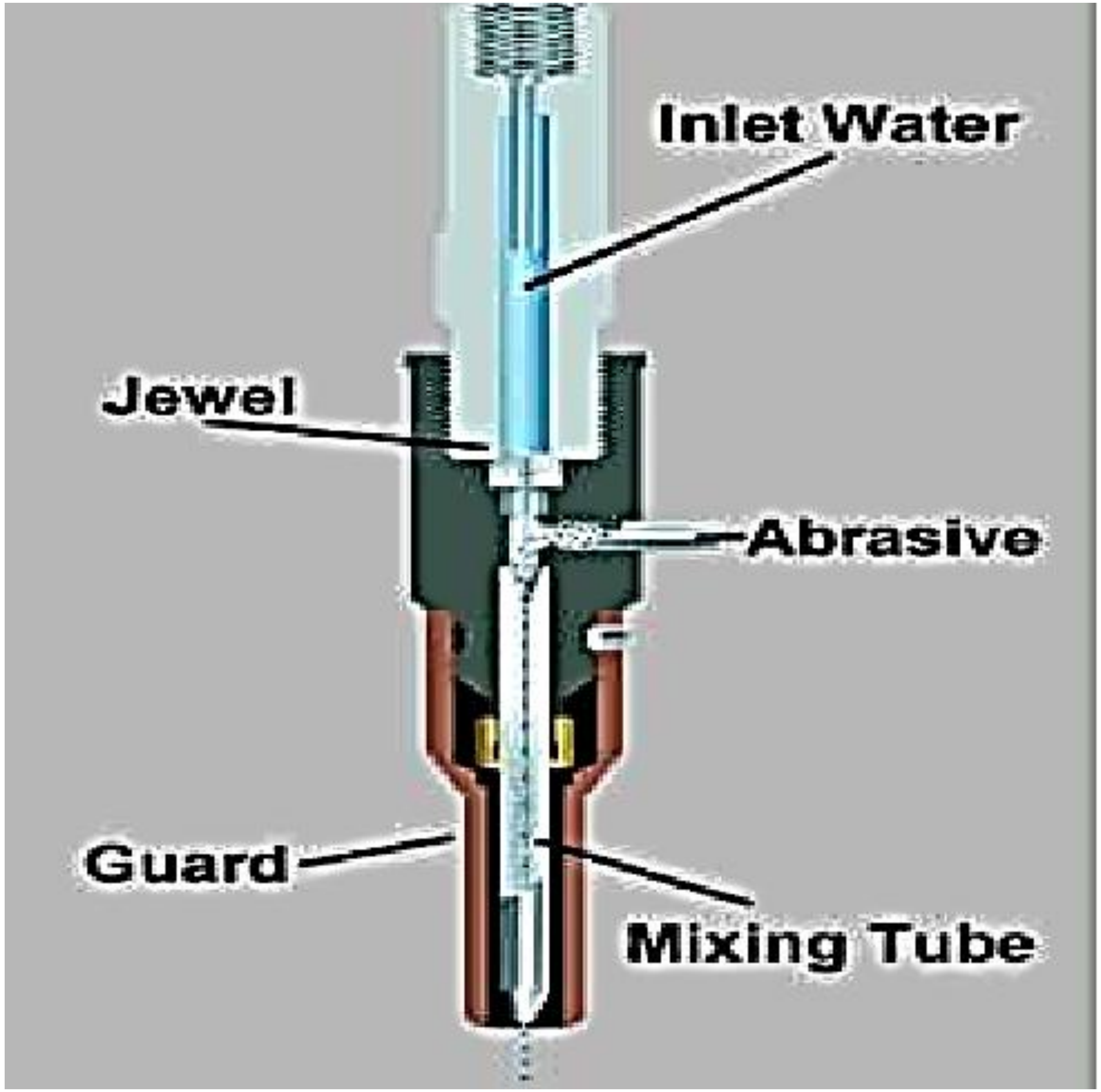
- Water is pumped at sufficiently high pressure ,200-400 MPA (2000-4000 bar) using a intensifier technology.
- Intensifier – pressure amplification using hydraulic cylinders of different cross sections – **"Jute Bell Presses".**
- Water is issued through a suitable orifice (0.2 to 0.4 mm dia.), the P.E is converted into K.E. resulting in high velocity jet (1000 m/s).
- **Pure WJM** – commercial tap water is used, jet entrains atmospheric air and flares out.
- **AWJM** – Abrasive particles are entrained in water (silicon oxide/glass beads etc.) – 800 m/s – can machine almost any material.

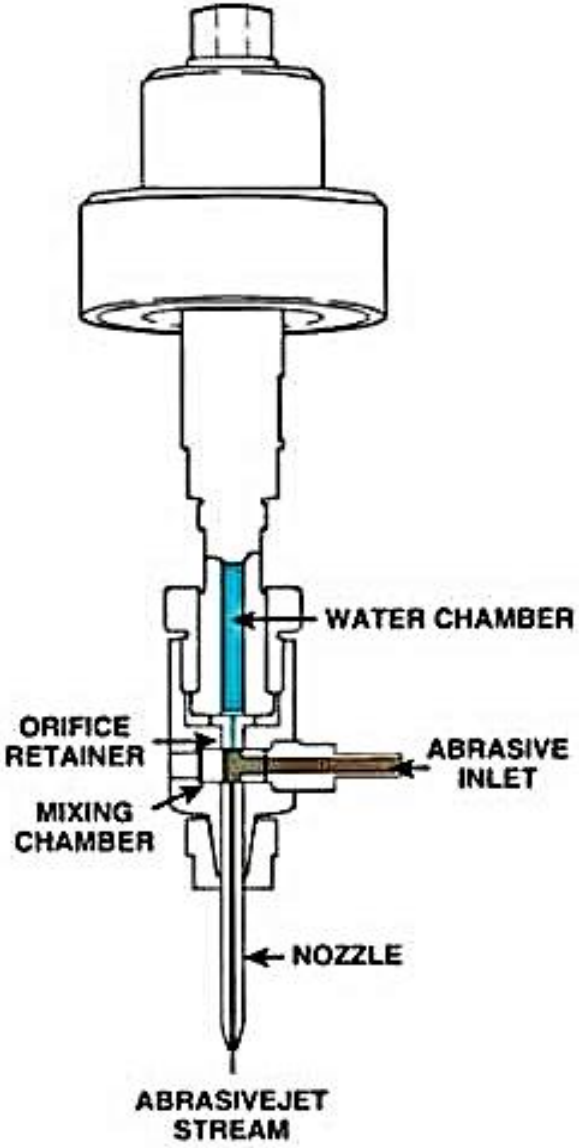
Nozzle

- Abrasive particles are gradually accelerated due to the transfer of momentum from the water phase to abrasive phase and when jet leaves the focusing tube , water and jet are assumed to be at same velocity.
- Focusing tube – WC .
- ID – 0.8 to 1.6mm
- Length – 50 to 80 mm



Nozzle


Inlet Water
Jewel
Abrasive
Guard
Mixing Tube


WATER CHAMBER
ORIFICE RETAINER
ABRASIVE INLET
MIXING CHAMBER
NOZZLE
ABRASIVEJET STREAM

Nozzle

- Entrained type AJWM - In entrained AWJM, the abrasive water jet, which finally comes from the focussing tube or nozzle, can be used to machine different materials.
- Suspended type AJWM –

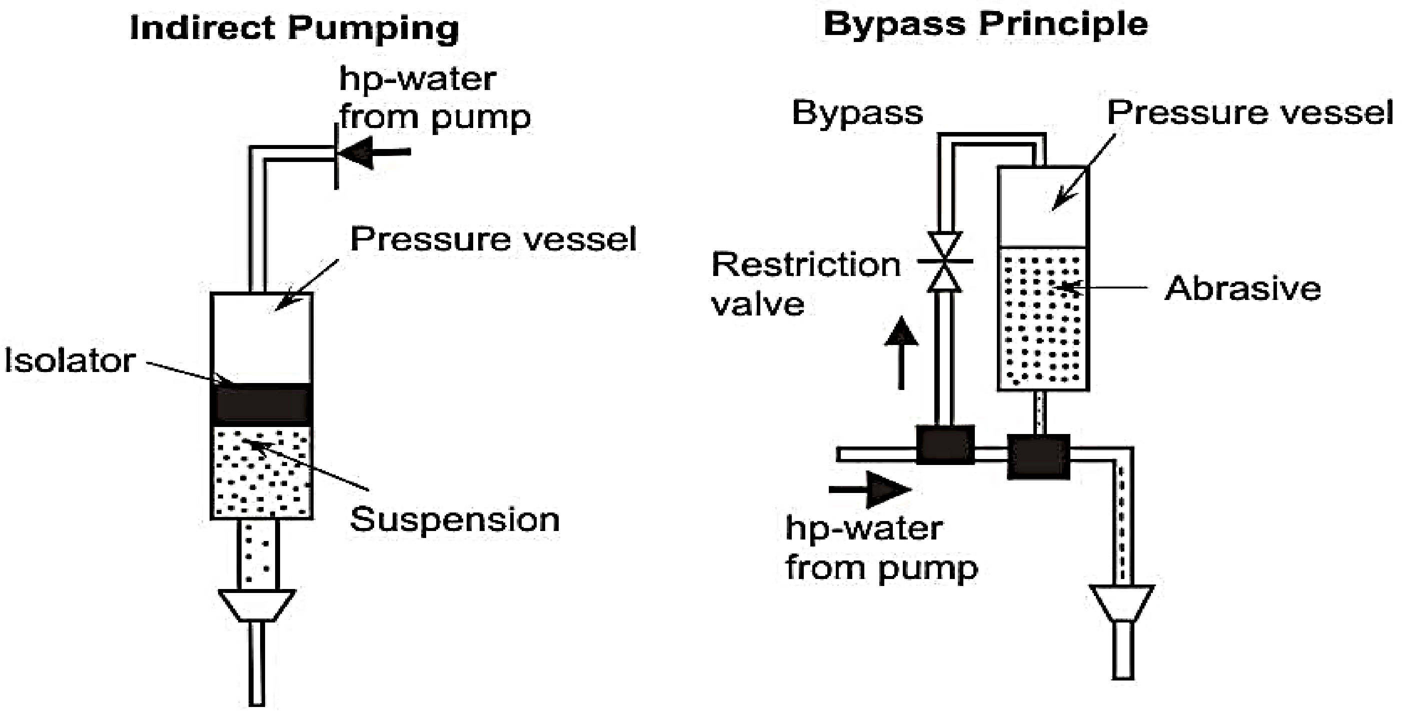


Fig. 8
Schematic of AWJM (Suspension type)

Mechanism of metal removal

- Brittle materials – crack initiation and propagation- brittle failure.
- **Process parameters:**
  - Orifice – Sapphires – 0.1 to 0.3 mm
  - Focusing Tube – WC – 0.8 to 2.4 mm
  - Pressure – 2500 to 4000 bar
  - Abrasive – garnet and olivine
  - Abrasive flow - 0.1 to 1.0 Kg/min
  - Stand off distance – 1 to 2 mm
  - Machine Impact Angle – 60^{o} to 90^{0}
  - Traverse Speed – 100 mm/min to 5 m/min
  - Depth of Cut – 1 mm to 250 mm

Applications

- Paint removal
- Cutting soft materials
- Cutting frozen meat
- Textile, Leather industry
- Mass Immunization
- Surgery
- Peening
- Cutting
- Pocket Milling
- Drilling

Advantages

- Cut virtually any material. (pre hardened steel, mild steel, copper, brass, aluminum; brittle materials like glass, ceramic, quartz, stone)
- Cut thin stuff, or thick stuff.
- Make all sorts of shapes with only one tool.
- No heat generated.
- Leaves a satin smooth finish, thus reducing secondary operations.
- Clean cutting process without gasses or oils.
- Modern systems are now very easy to learn.
- Are very safe.
- Machine stacks of thin parts all at once.

- 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

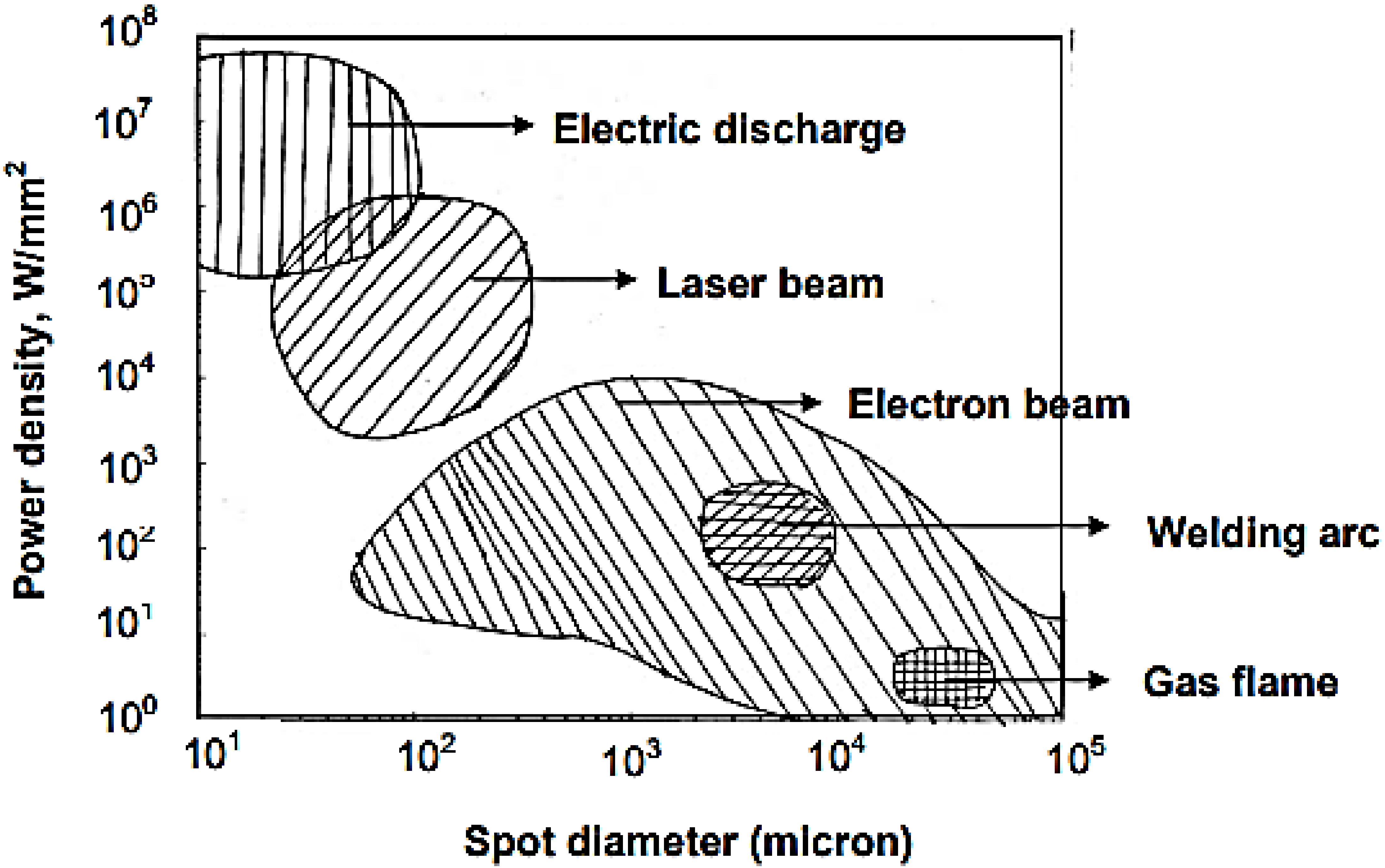
- Limited number of materials can be cut economically. While it is possible to cut tool steels, and other hard materials, the cutting rate has to be greatly reduced, and the time to cut a part can be very long.
- Because of this, waterjet cutting can be very costly and outweigh the advantages.

- Very thick parts can not be cut with waterjet 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.

Non-Conventional Processes

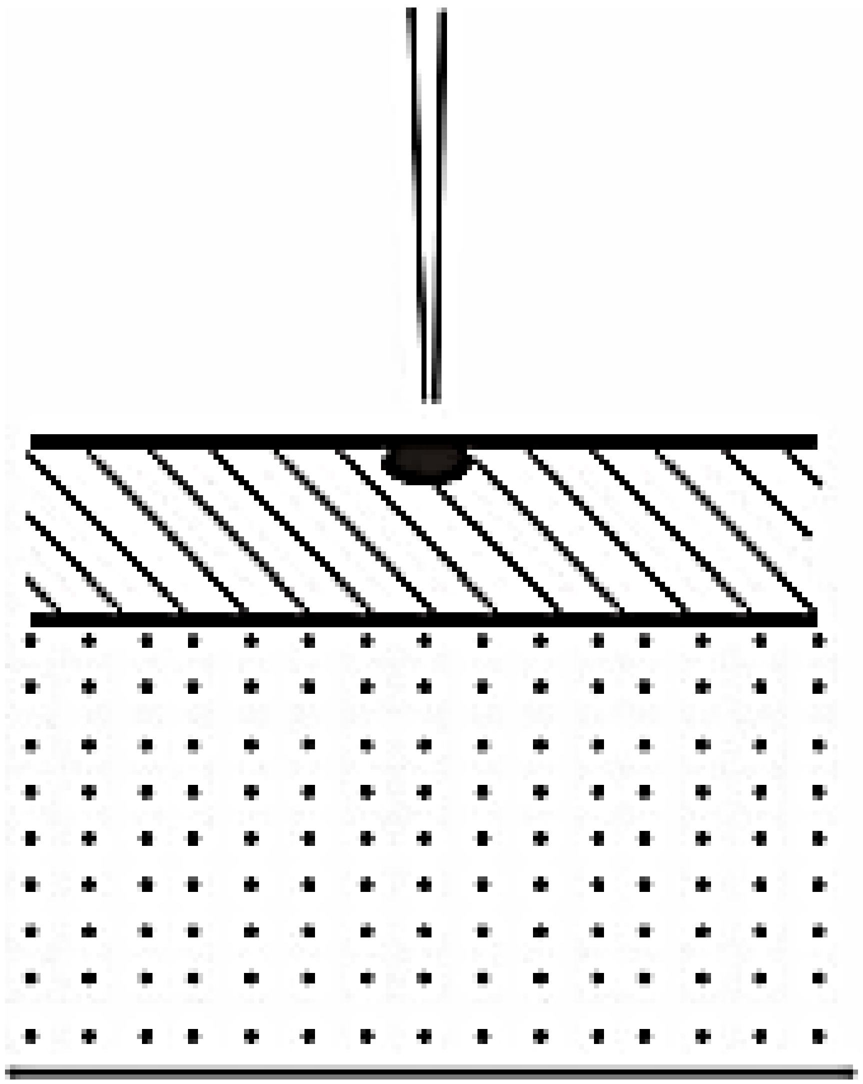
Electro-optical-thermal processes

- *ELECTRON BEAM MACHINING*
- *LASER BEAM MACHINING*

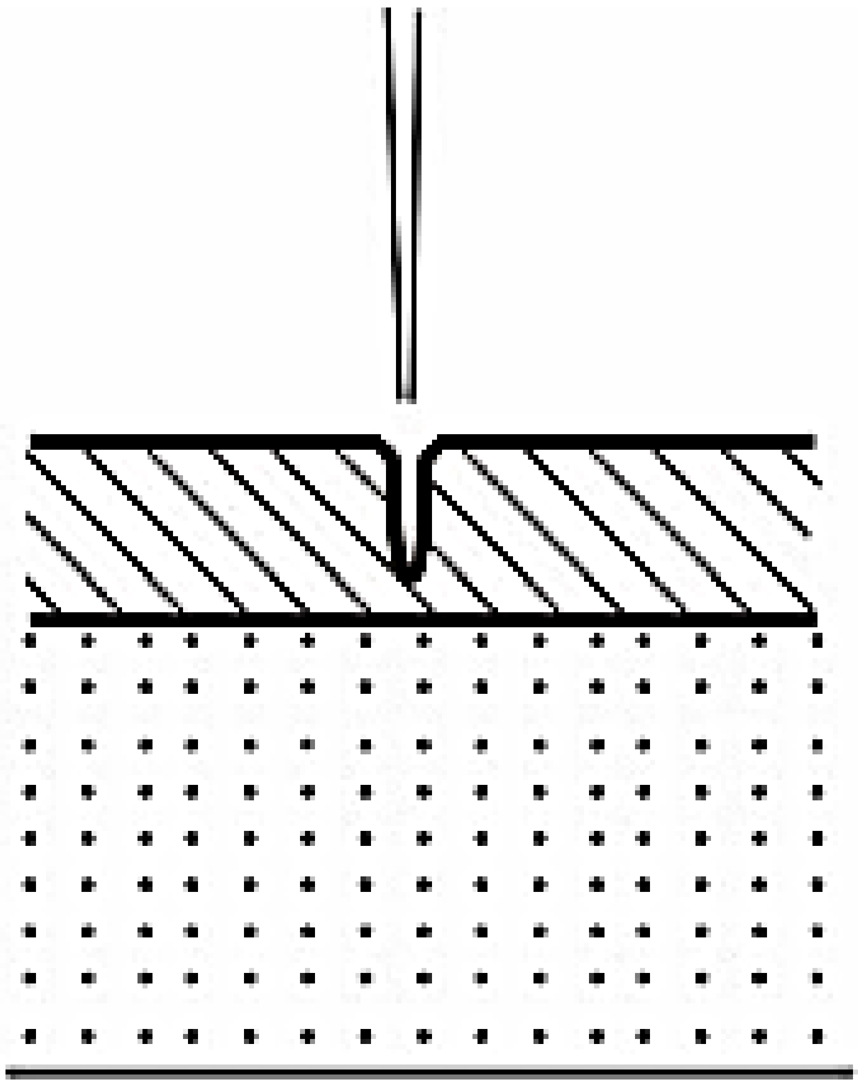

Power density, W/mm²
10⁸
10⁷
10⁶
10⁵
10⁴
10³
10²
10¹
10⁰
Electric discharge
Laser beam
Electron beam
Welding arc
Gas flame
10¹
10²
10³
10⁴
10⁵
Spot diameter (micron)

- ✓ Electron Beam Machining (EBM) and Laser Beam Machining (LBM) are thermal processes considering the mechanisms of material removal.

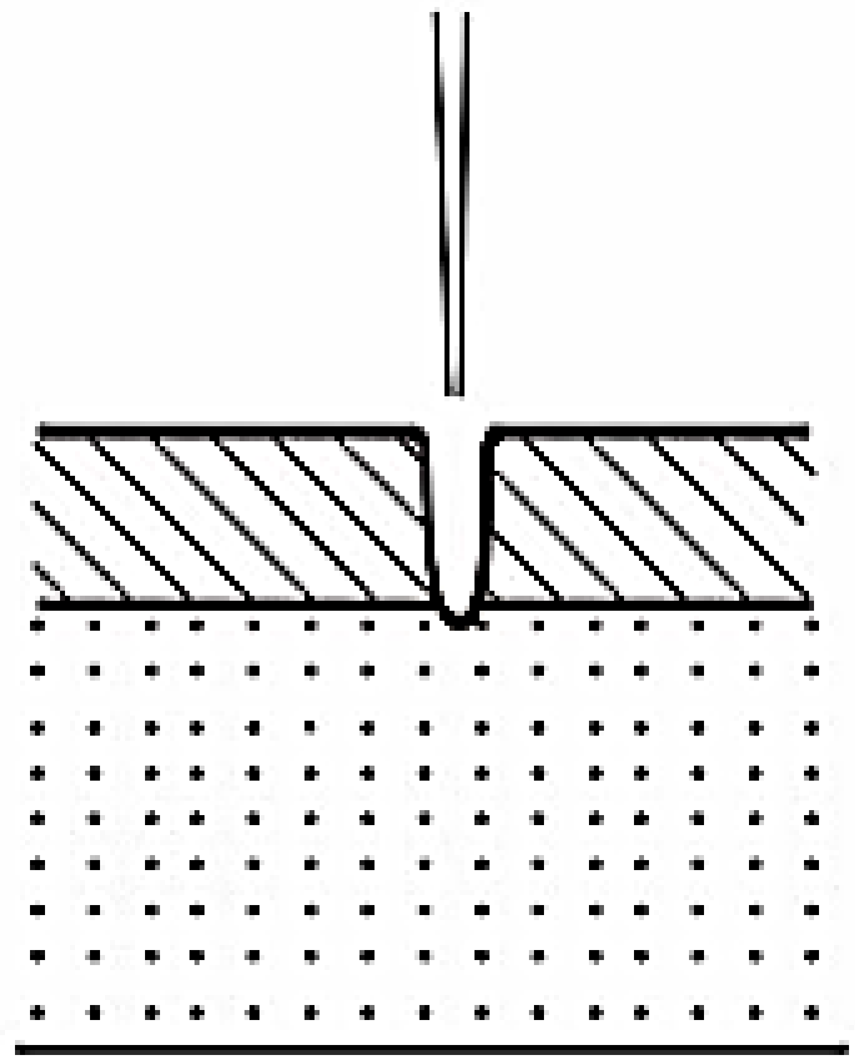
- ✓ However electrical energy is used to generate high-energy electrons in case of Electron Beam Machining (EBM) and high-energy coherent photons in case of Laser Beam Machining (LBM).



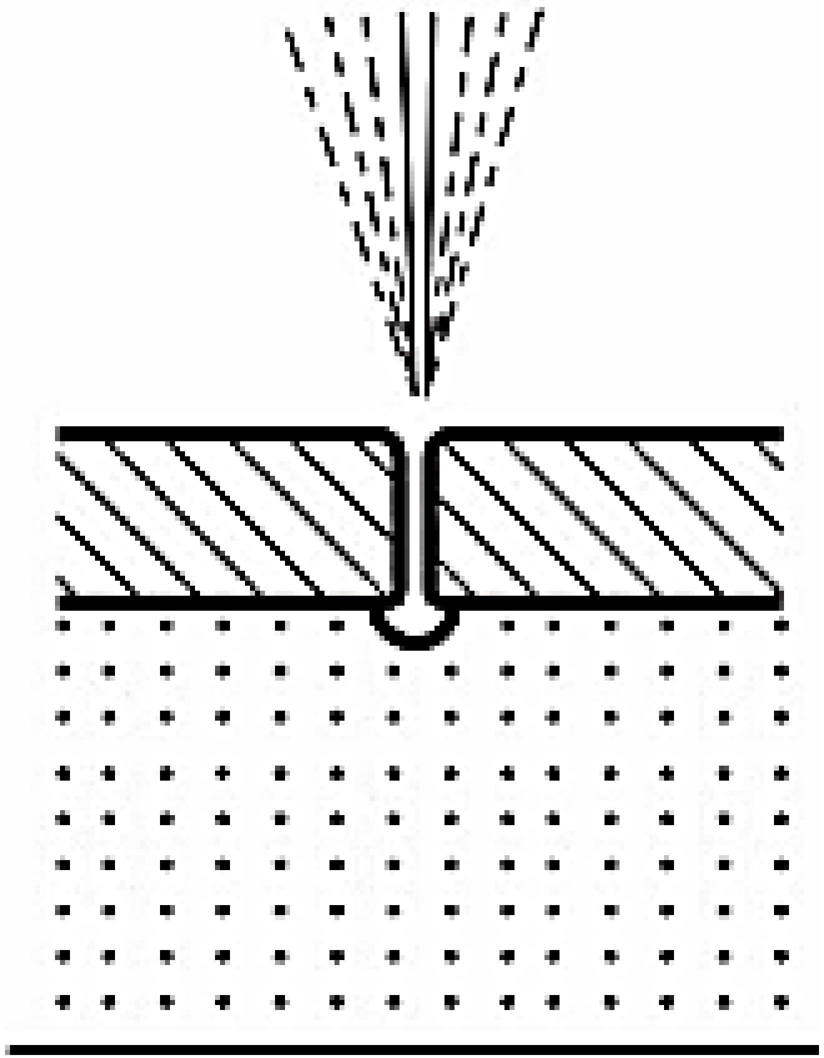
Localized heating by focused electron beam



Gradual formation of hole



Penetration till the auxiliary support



Removal due to high vapour pressure

- Electron beam is generated in an electron beam gun.

- Electron beam gun provides high velocity electrons over a very small spot size.

- Electron Beam Machining is required to be carried out in vacuum. Otherwise the electrons would interact with the air molecules, thus they would loose their energy and cutting ability.

- Thus the workpiece to be machined is located under the electron beam and is kept under vacuum.

- High-energy focused electron beam is made to impinge on the workpiece with a spot size of 10 – 100 μm.

- Kinetic energy of the high velocity electrons is converted to heat energy as the electrons strike the work material.

- Due to high power density instant melting and vaporisation starts and "melt – vaporisation" front gradually progresses.

- Finally the molten material, if any at the top of the front, is expelled from the cutting zone by the high vapour pressure at the lower part.

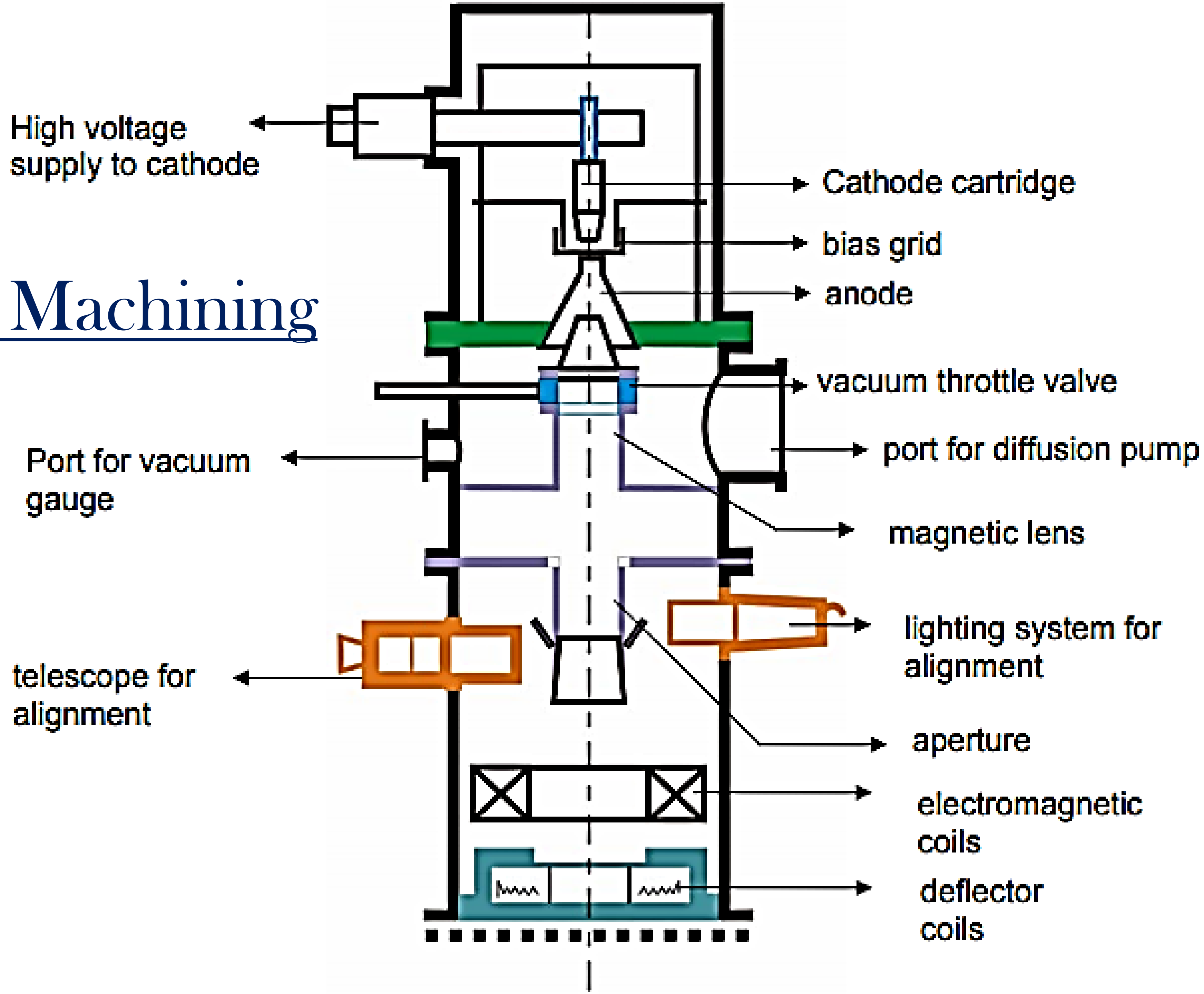
- Unlike in Electron Beam Welding, the gun in EBM is used in pulsed mode.

- Holes can be drilled in thin sheets using a single pulse.

- For thicker plates, multiple pulses would be required.

- Electron beam can also be manoeuvred using the electromagnetic deflection coils for drilling holes of any shape.

Electron Beam Machining – Equipment



- Basic functions of any electron beam gun are to generate free electrons at the cathode, accelerate them to a sufficiently high velocity and to focus them over a small spot size.

- Further, the beam needs to be manoeuvred if required by the gun.
- The cathode is generally made of tungsten or tantalum.

- Such cathode filaments are heated, often inductively, to a temperature of around 25000°C.

- Such heating leads to thermo-ionic emission of electrons, which is further enhanced by maintaining very low vacuum within the chamber of the electron beam gun.

- Moreover, this cathode cartridge is highly negatively biased so that the thermo-ionic electrons are strongly repelled away form the cathode.
- This cathode is often in the form of a cartridge so that it can be changed very quickly to reduce down time in case of failure.

- Just after the cathode, there is an annular bias grid.
- A high negative bias is applied to this grid so that the electrons generated by this cathode do not diverge and approach the next element, the annular anode, in the form of a beam.
- The annular anode now attracts the electron beam and gradually gets accelerated.

- As they leave the anode section, the electrons may achieve a velocity as high as half the velocity of light.

- The nature of biasing just after the cathode controls the flow of electrons and the biased grid is used as a switch to operate the electron beam gun in pulsed mode.

- After the anode, the electron beam passes through a series of magnetic lenses and apertures.

- The magnetic lenses shape the beam and try to reduce the divergence. Apertures on the other hand allow only the convergent electrons to pass and capture the divergent low energy electrons from the fringes.

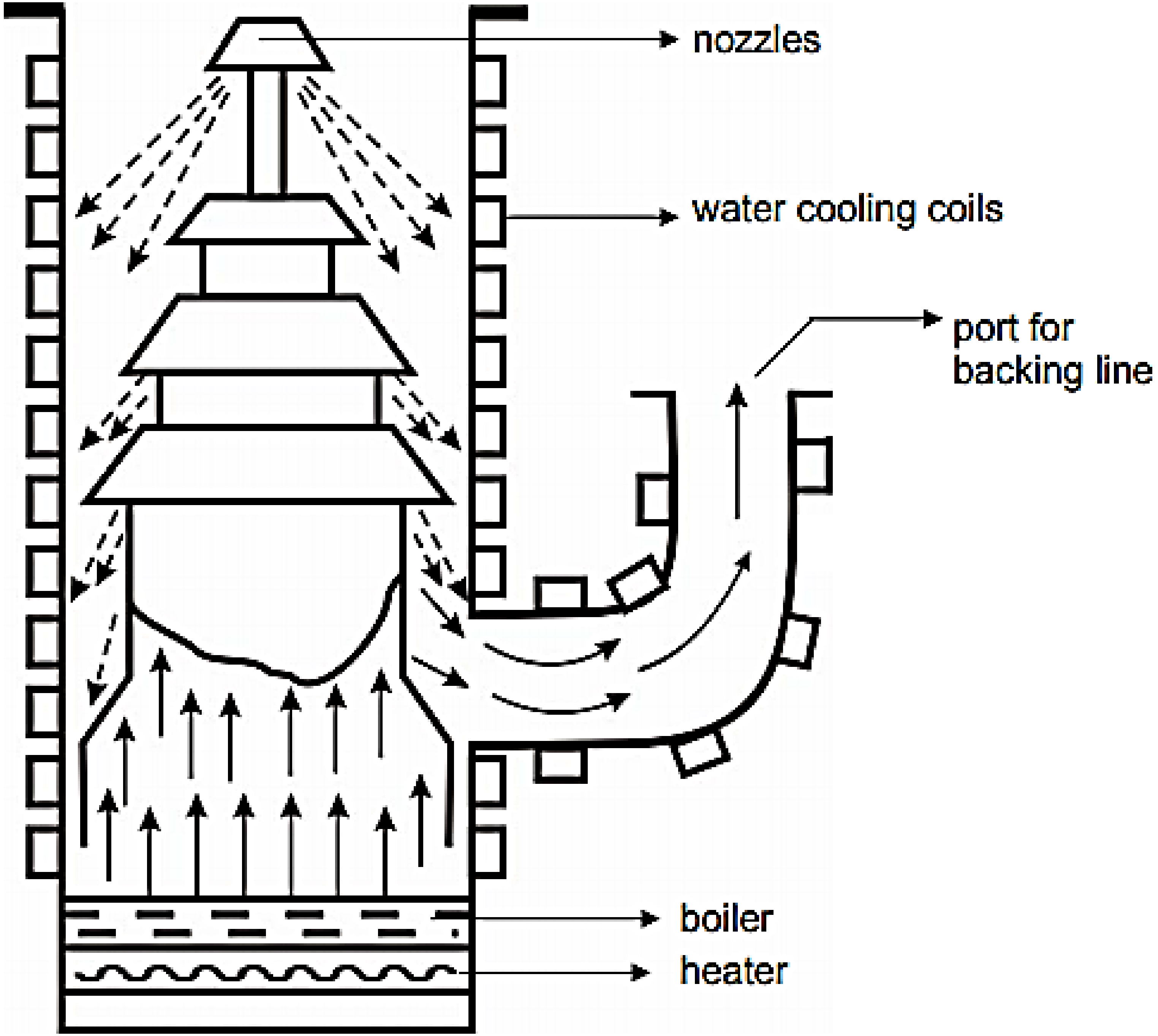
- This way, the aperture and the magnetic lenses improve the quality of the electron beam.

- Then the electron beam passes through the final section of the electromagnetic lens and deflection coil.
- The electromagnetic lens focuses the electron beam to a desired spot.
- The deflection coil can manoeuvre the electron beam, though by small amount, to improve shape of the machined holes.
- Generally in between the electron beam gun and the workpiece, which is also under vacuum, there would be a series of slotted rotating discs.
- Such discs allow the electron beam to pass and machine materials but helpfully prevent metal fumes and vapour generated during machining to reach the gun.
- Thus it is essential to synchronize the motion of the rotating disc and pulsing of the electron beam gun.

- Electron beam guns are also provided with illumination facility and a telescope for alignment of the beam with the workpiece.

- Workpiece is mounted on a CNC table so that holes of any shape can be machined using the CNC control and beam deflection in-built in the gun.

Working of DIFFUSION pump



- Diffusion pump is essentially an oil heater. As the oil is heated the oil vapour rushes upward where gradually converging structure.
- Nozzles change the direction of motion of the oil vapour and the oil vapour starts moving downward at a high velocity as jet.
- Such high velocity jets of oil vapour entrain any air molecules present within the gun.
- This oil is evacuated by a rotary pump via the backing line.
- The oil vapour condenses due to presence of cooling water jacket around the diffusion pump.

Electron Beam Process – Parameters

- The accelerating voltage
- The beam current
- Pulse duration
- Energy per pulse
- Power per pulse
- Lens current
- Spot size
- Power density

Typical kerf shape of electron beam drilled hole