Jet Machining Operations

ME312: Manufacturing Technologies - II
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Classification of Mechanical Abrasive Processes

- **Mechanical Abrasive Processes**
  - Ultrasonic Machining
  - Water Jet Machining
  - Abrasive Jet Machining
  - Abrasive Water Jet Machining
  - Abrasive Flow Machining

Jet Machining Operations: Water Jet Machining, Abrasive Jet Machining, Abrasive Water Jet Machining

Water Jet Machining (WJM)

- Removes material through the erosion effects of a high velocity, small diameter jet of water
- When the stream strikes a workpiece surface, the erosive force of water removes the material rapidly.
- The water, in this case, acts like a saw and cuts a narrow groove in the workpiece material.

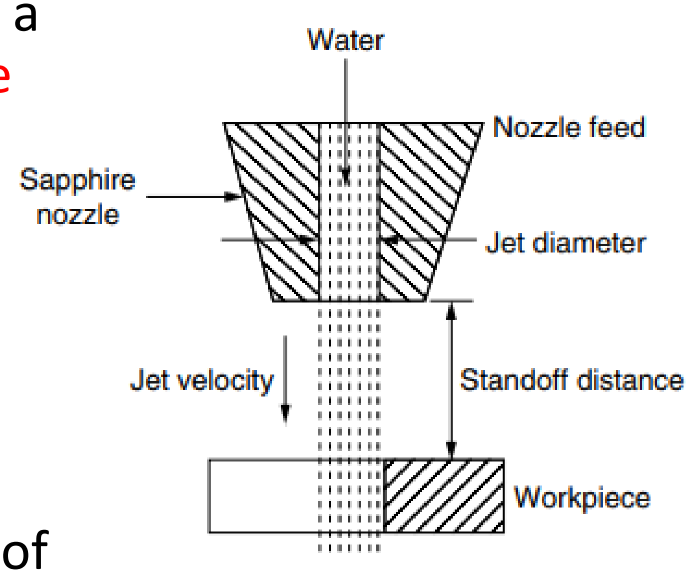


History

- The principle behind this method of cutting was first observed in the early 1900s by workers in steam plant
- No significant effort was made to apply this technology until the 1960s when Norman Franz patented the technique for producing a coherent, high-velocity stream of water
- This became the basis for today's WJM technology, was refined during the 1960s
- WJM was first introduced to industry as a new cutting tool in the early 1970s

Process Description

- Also known as Hydrodynamic Machining
- WJM is a form of micro erosion. It works by forcing a large volume of water through a small orifice in the nozzle.
- The key element in water jet machining (WJM) is a water jet, which travels at velocities as high as 900 m/s (approximately Mach 3).
- At the target, the kinetic energy of the jet is converted spontaneously to high-pressure energy, inducing high stresses exceeding the flow strength of target material, causing mechanical abrasion.

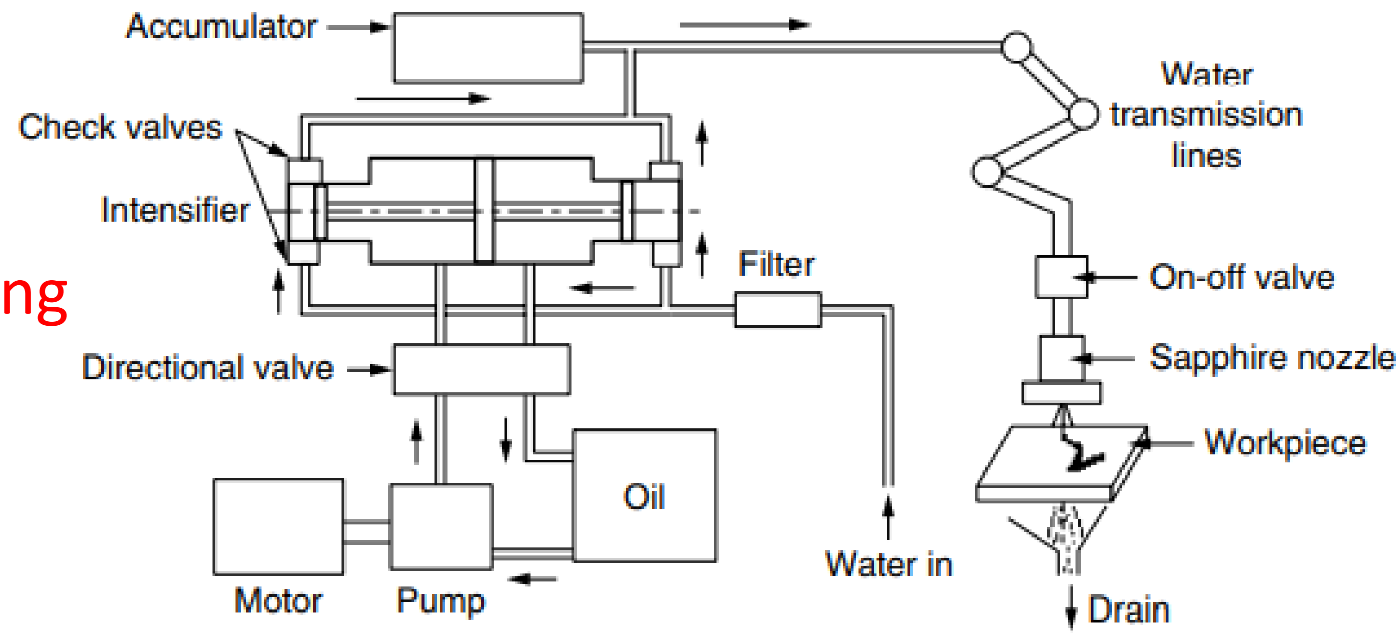


Process Description

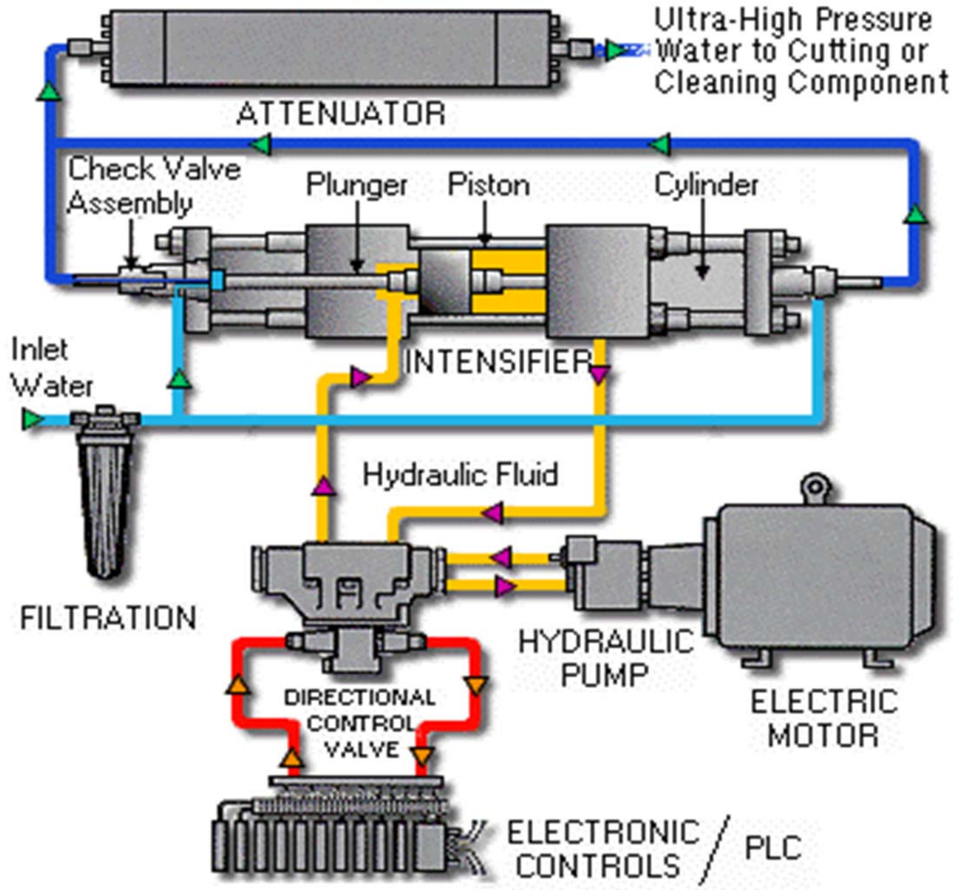
- Water jet machining provides omnidirectional cutting capabilities at very high speeds with a resulting edge quality
- For machining softer materials such as plastics and fibers simple water jet machining is used.
- Unlike conventional processes, downtime for the replacement of worn or broken cutting tools is virtually nonexistent with WJM because the “tool” never dulls or breaks
- Additionally, the health hazards associated with cutting materials such as asbestos and fiberglass are minimized because almost no airborne dust is generated by this process

Machine Components

- Hydraulic Pump
- Intensifier
- Accumulator
- High Pressure Tubing
- Jet Cutting Nozzle
- Catcher



Working of WJM



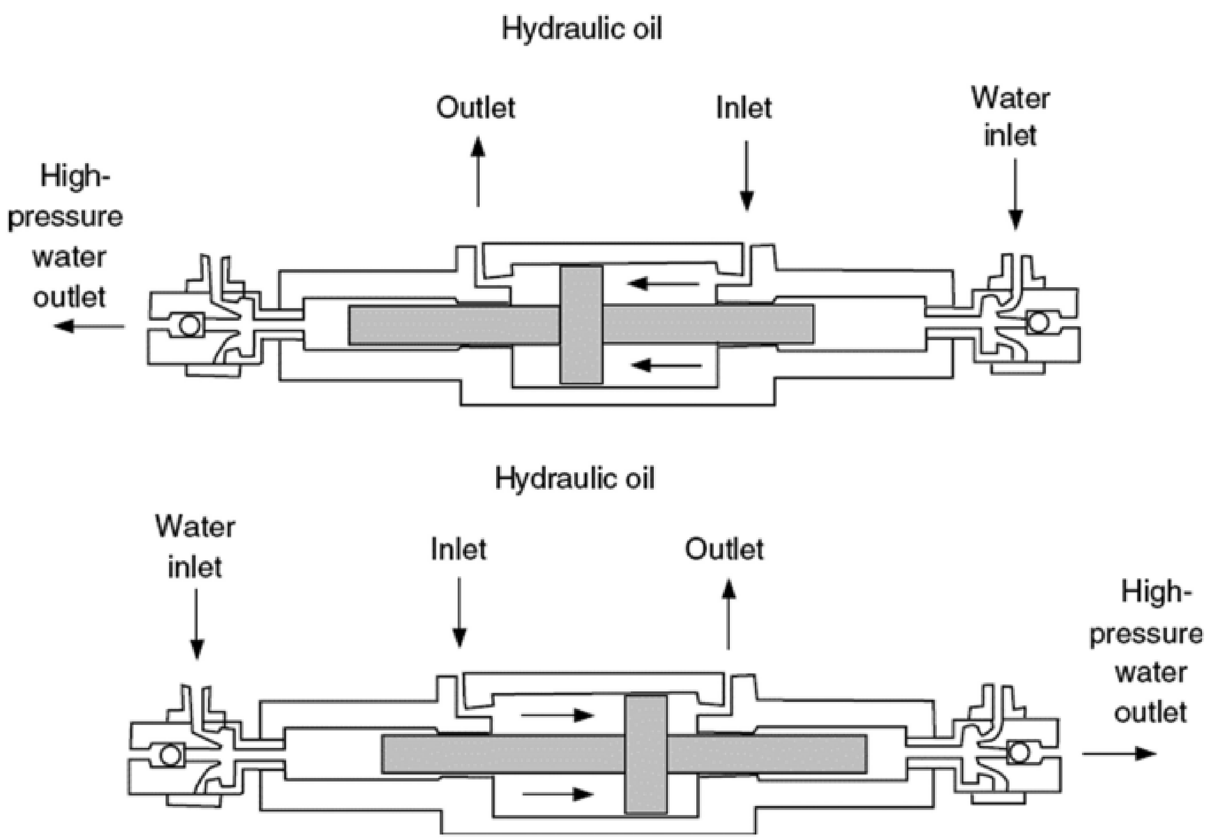
Hydraulic Pump

- Powered from a 15-37 kilowatt (kW) electric motor
- Supplies oil at pressures as high as 117 bars.
- Compressed oil drives a plunger pump termed an intensifier.
- The hydraulic pump offers complete flexibility for water jet cutting and cleaning applications.
- It also supports single or multiple cutting stations for increased machining productivity.

Intensifier

- The intensifier converts the energy from the low-pressure hydraulic fluid into ultrahigh-pressure water.
- The water directly supplied to the small cylinder of the intensifier at low pressure(typically 4 bar)
- It delivers water at higher pressures of 3800 bar through an accumulator
- The hydraulic system provides fluid power to piston in the intensifier center section
- A limit switch, located at each end of the piston travel, signals the electronic controls to shift the directional control valve and reverses the piston direction.
- The intensifier assembly, with a plunger on each side of the piston, generates pressure in both directions.

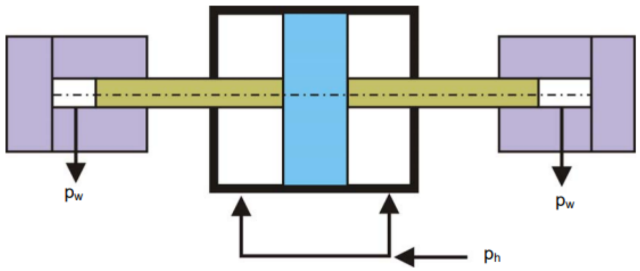
Intensifier



Intensifier

- As one side of the intensifier is in the inlet stroke, the opposite side is generating ultrahigh-pressure output.
- During the plunger inlet stroke, filtered water enters the high-pressure cylinder through the check value assembly.
- After the plunger reverses direction, the water is compressed and exits at ultrahigh pressure.

$$p_h A_{large} = p_w A_{small}$$



Water pressure: $p_w = p_h \dfrac{A_{large}}{A_{small}}$

Accumulator

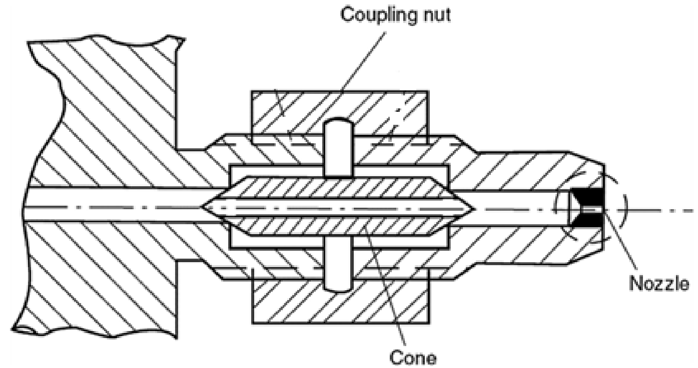
- Water compresses approximately 15% at the intensifier's output pressure causing reduced water flow at the beginning of each piston stroke.
- The accumulator is simply a pressure vessel that stores high-pressure water
- Avoids pulsations and maintains the continuous flow of the high-pressure water
- Eliminates pressure fluctuations and assures that the final output flow is smooth.
- Maintains output pressure variations of not more than ± 5%

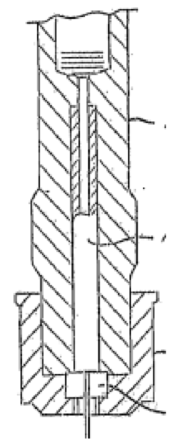
High Pressure Tubing

- Transports pressurized water to the cutting head.
- Typical tube diameters are 6 to 14 mm.
- Rigid tubing is used because no flexible tubing is currently manufactured that will handle pressures above 2000 bar
- The equipment allows for flexible movement of the cutting head.
- The cutting action is controlled either manually or through a remote-control valve specially designed for this purpose.

Jet Cutting Nozzle

- The cutting nozzle converts the ultrahigh pressure (about 4000 bar) into a high speed of 400 to 1400 m/s
- Nozzle provides a coherent water jet stream for optimum cutting
- Nozzles are generally made from very hard materials such as WC, synthetic sapphire, or diamond
- Nozzle becomes damaged by particles of dirt and the accumulation of mineral deposits on the orifice due to erosive water hardness
- A longer nozzle life can be obtained through multistage filtration
- Nozzle hole diameters typically range from 0.07 to 0.5 mm and sometimes may be as large as 1.0 mm

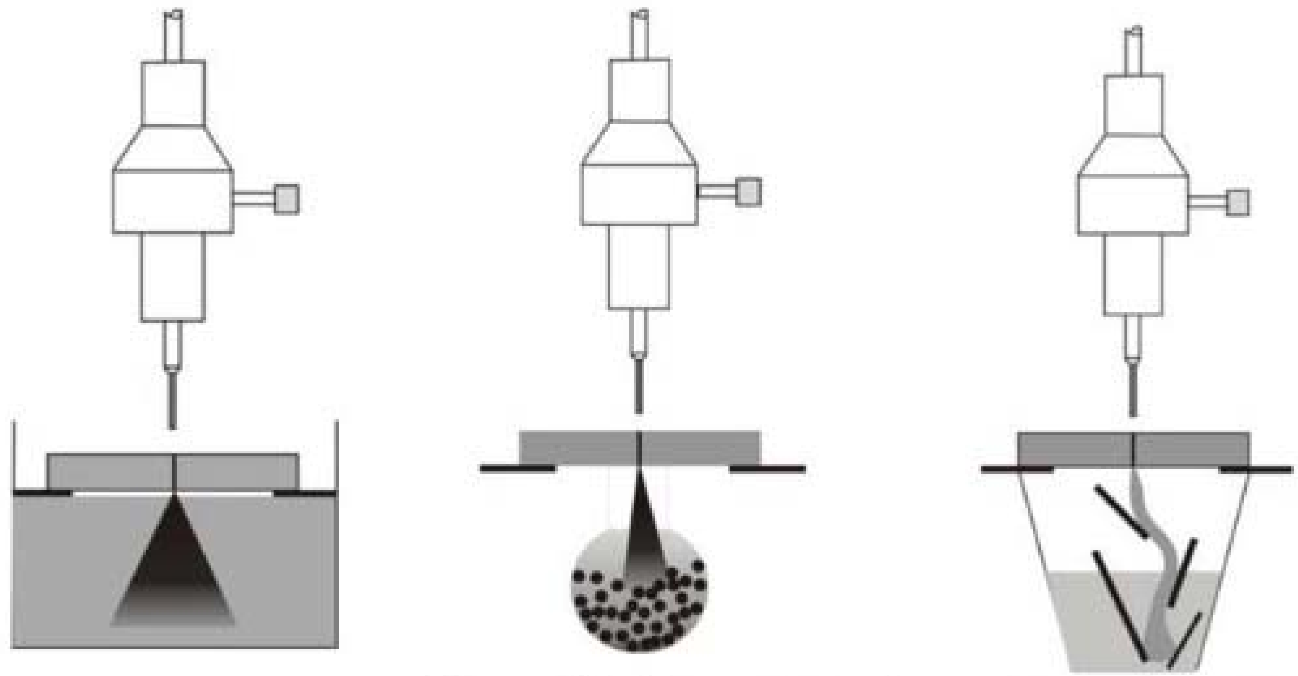




Drain or Catcher

- Acts as a reservoir for collecting the machining debris entrained in the water jet.
- Absorbs the rest energy after cutting which is estimated to be 90% of the total jet energy.
- Water breaking up into mist and droplets at this speed and into an open area can produce sound as loud as 130 dBA
- Reduces the noise levels associated with the reduction in the velocity of the water jet from Mach 3 to subsonic levels.
- Therefore, to minimize noise, either a tube or slot-type catcher is used beneath the point of the cut.

Drain or Catcher



(a) water basin (b) steel/WC/ceramic balls (c) catcher plates (TiB_2)

Determination of water jet velocity

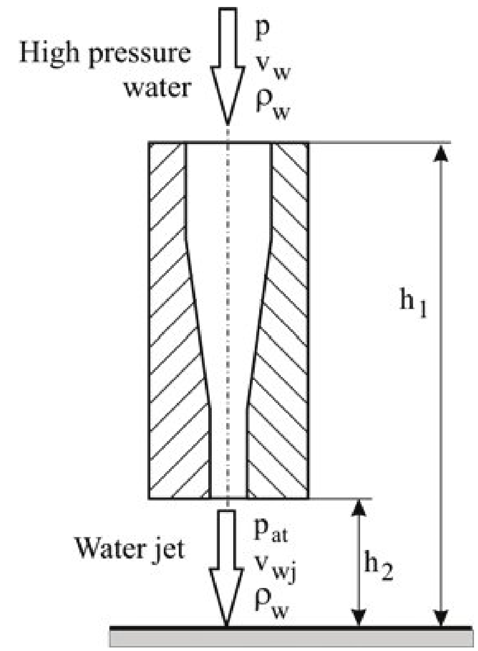
$$p_w + \frac{\rho_w V_w^2}{2} + \rho_w \mathrm{g}h = \text{constant}$$

$$p_w + \frac{\rho_w V_w^2}{2} + \rho_w \mathrm{g}h_1 = p_{at} + \frac{\rho_w V_{wj}^2}{2} + \rho_w \mathrm{g}h_2$$

$$p_w - p_{at} = \frac{1}{2}\rho_w\left(V_{wj}^2 - V_w^2\right) + \rho_w \mathrm{g}(h_1 - h_2)$$

For $p_{at} \ll p_w; V_{wj} \gg V_w; h_1 \approx h_2$

$$p_w = \frac{1}{2}\rho_w V_{wj}^2$$



Material Removal Rate

- Considering the energy loss during water jet formation at the orifice,

Water jet velocity

$$p_w = \frac{1}{2}\rho_w V_{wj}^2 \rightarrow V_{wj} = \sqrt{\frac{2p_w}{\rho_w}}$$

- MRR Depend on reactive power of the Water jet

$$MRR \propto P_{wj}$$

Reactive power is equal to pressure (p_w) multiplied by volume flow rate($\dot{Q}_w$)

$$P_{wj} = p_w \dot{Q}_w$$

Material Removal Rate

The volume flow rate of water may be expressed as

$$\dot{Q}_w = c_d V_{wj} A_{orifice}$$

$$\dot{Q}_w = c_d \frac{\pi}{4} d_0^2 \sqrt{\frac{2p_w}{\rho_w}}$$

c_d =Discharge coefficient of the orifice

Material Removal Rate

The total power of the water jet can be given as

$$P_{wj} = p_w \dot{Q}_w$$

$$P_{wj} = p_w c_d \frac{\pi}{4} d_0^2 \sqrt{\frac{2p_w}{\rho_w}}$$

$$P_{wj} = c_d \frac{\pi}{4} d_0^2 \sqrt{\frac{2{p_w}^3}{\rho_w}}$$

Material Removal Rate:

$$MRR \propto P_{wj}$$

$$MRR = \left(\frac{1}{u}\right) c_d \frac{\pi}{4} d_0^2 \sqrt{\frac{2{p_w}^3}{\rho_w}}$$

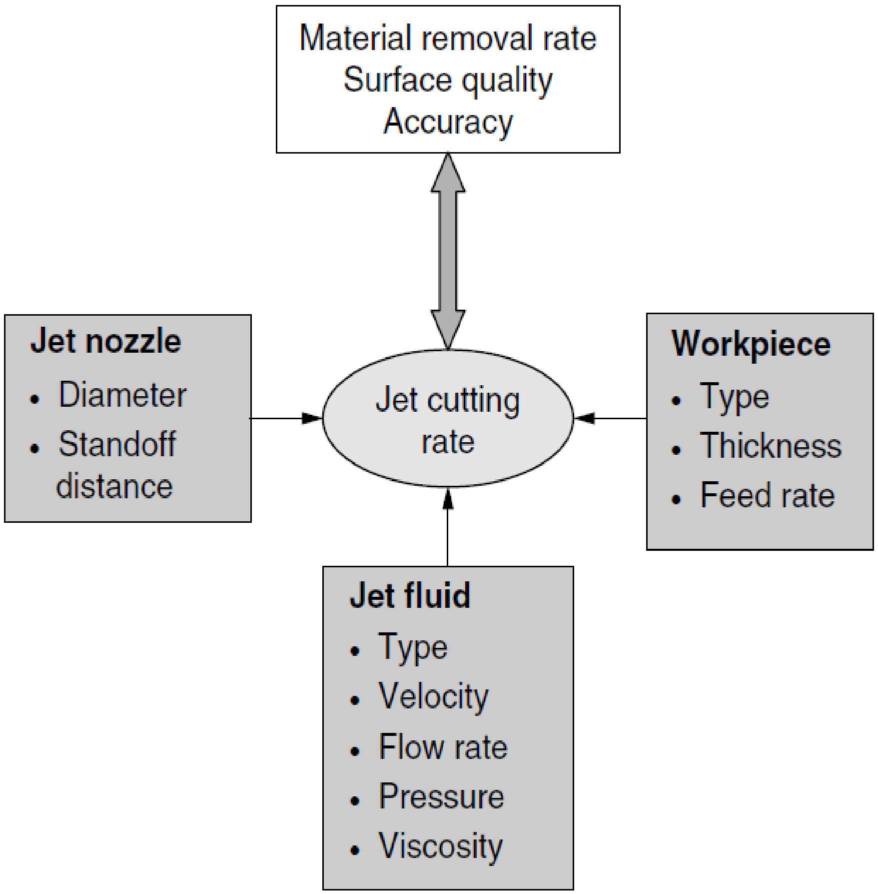
u is the specific energy requirement and would be a property of the work material.

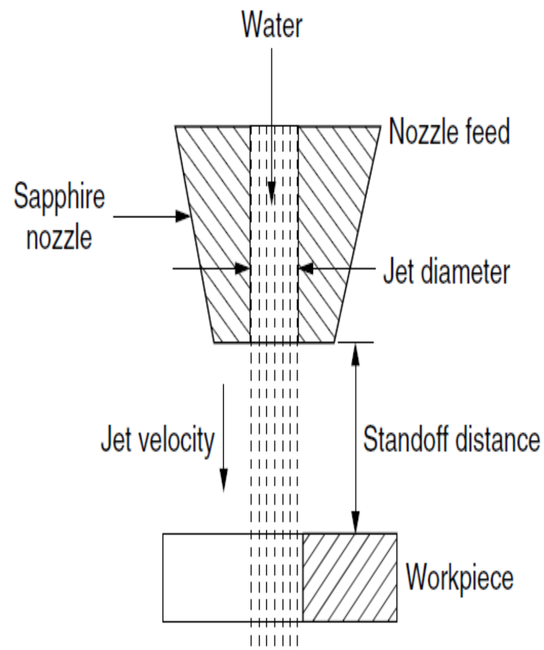
Questions

- Assuming no losses, determine water jet velocity, when the water pressure is 4000 bar, being issued from an orifice of diameter 0.3 mm

- Determine the mass flow rate of water for the given problem assuming all related coefficients to be 1.

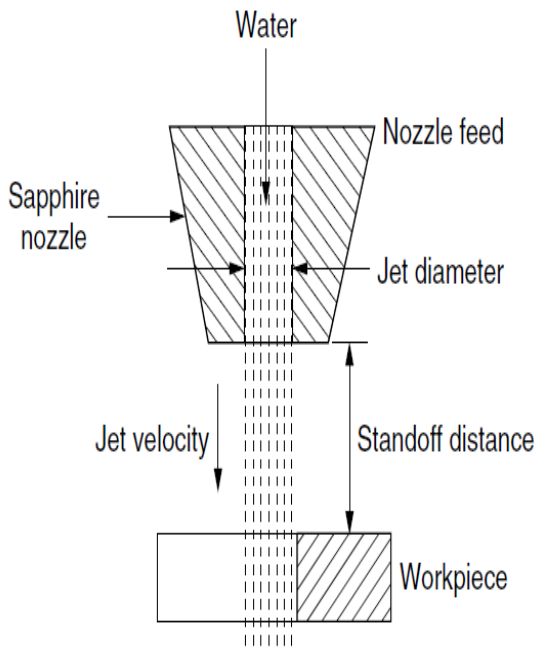
Parameters affecting the performance of WJM





Process Parameters

- Standoff distance - Gap between the jet nozzle (0.1–0.3 mm diameter) and the workpiece (2.5 – 6 mm)
- For material used in printed circuit boards, it may be increased up to 25 mm
- For larger standoff distance, the depth of cut would be smaller
- The increase in machining rate and use of the small nozzle diameter may increase the width of the damaged layer.



Jet parameters

- Typical pressures used are 1500 to 8000 bar to provide 8 to 80 kW of power.
- Increase in pressure allows more power to be used in the machining process, which in turn increases the depth of the cut.
- Jet velocities range between 540 to 1400 m/s.
- The quality of cutting improves at higher pressures by widening the diameter of the jet and by lowering the traverse speed
- Under such conditions, materials of greater thicknesses and densities can be cut
- The fluid used must possess low viscosity to minimize the energy losses and be noncorrosive, and nontoxic
- Water is commonly used

Workpiece

- Brittle materials will fracture, while ductile ones will cut well
- Material thicknesses range from 0.8 to 25 mm or more

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

Advantages

- Water is cheap, non-toxic, and can be easily disposed and recirculated
- The process requires limited volume of water (100–200 l/hr)
- The tool (nozzle) does not wear and, therefore, does not need sharpening
- It is a versatile and cost-effective cutting process that can be used as an alternative to traditional machining methods.
- It completely eliminates heat-affected zones, toxic fumes, recast layers, work hardening and thermal stresses.
- It is the most flexible and effective cleaning solution available for a variety of industrial needs.
- It is ideal for cutting asbestos, glass fiber insulation, beryllium, and fiber reinforced plastics (FRP), because the process provides a dustless atmosphere
- The process provides clean and sharp cuts, free from burrs.
- It is applicable for laser reflective materials such as, glass, copper, and aluminum.

Limitations

- WJM is not safe in operation if safety precautions are not strictly followed.
- The process is characterized by a high production cost due to:
  - High capital cost of the machine
  - The need of highly qualified operators
- WJM is not adapted to mass production because of the high maintenance requirement.

Applications

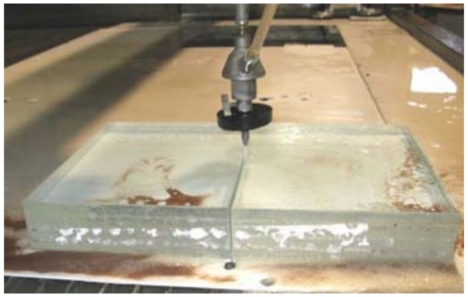
- It is ideal in cutting soft materials such as wood, paper, cloth, leather, rubber, and plastics
- Cutting of fibreglass and corrugated wood.
- Cutting of metals and composites applied in aerospace industries
- Underwater cutting and shipbuilding industries
- Cutting of rocks, granite, and marble
- Slicing and processing of frozen foods, baked foods, and meat. In such cases, alcohol, glycerin, and cooking oils are used as alternative cutting fluids
- WJM is also used in:
  - Cleaning, polishing, and degreasing of surfaces
  - Removal of nuclear contaminations
  - Cleaning of tubes and castings
  - Surface preparation for inspection purposes
  - Surface strengthening
  - Deburring

WJM Parts

Cake Cutting

Fish

PCB Cutting



Bulletproof glass

Videos

- https://www.youtube.com/watch?v=AeOXILcl0Ws
- https://www.youtube.com/watch?v=QgJ0iV9gfG4
- https://www.youtube.com/watch?v=PIJaDaSClFw
- https://www.youtube.com/watch?v=KySnPZ5SoSM
- https://www.youtube.com/watch?v=3yV-uJHla58&t=1910s