

## 7.3 NON-TRADITIONAL PROCESSES

### *Traditional vs. non-traditional processes*

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

The principal characteristics of traditional machining processes (discussed in the previous sections), and non-traditional processes (some of them included in this section) is presented to compare their advantages and limitations:

- ❖ The cutting tool and workpiece are always in physical contact, with a relative motion against each other, which results in friction and a significant *tool wear*. In non-traditional processes, there is no physical contact between the tool and workpiece. Although in some non-traditional processes tool wear exists, it rarely is a significant problem;
- ❖ Material removal rate of the traditional processes is limited by the mechanical properties of the work material. Non-traditional processes easily deal with such difficult-to-cut materials like ceramics and ceramic based tool materials, fiber reinforced materials, carbides, titanium-based alloys;
- ❖ In traditional processes, the relative motion between the tool and workpiece is typically rotary or reciprocating. Thus, the shape of the work surfaces is limited to circular or flat shapes. In spite of widely used CNC systems, machining of three-dimensional surfaces is still a difficult task. Most non-traditional processes were developed just to solve this problem;
- ❖ Machining of small cavities, slits, blind or through holes is difficult with traditional processes, whereas it is a simple work for some non-traditional processes;
- ❖ Traditional processes are well established, use relatively simple and inexpensive machinery and readily available cutting tools. Non-traditional processes require expensive equipment and tooling as well as skilled labor, which increases significantly the production cost;

From the above it follows that non-traditional processes generally should be employed when

- ❖ there is a need to process some newly developed difficult-to-cut materials, machining of which is accompanied by excessive cutting forces and tool wear;
- ❖ there is a need for unusual and complex shapes, which cannot easily be machined or cannot at all be machined by traditional processes;

The non-traditional processes are often classified according to the principle form of energy used:

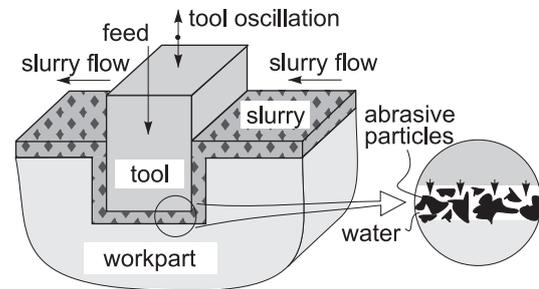
- ❖ *mechanical processes*: the mechanical energy differs from the action of the conventional cutting tool. Examples include *ultrasonic machining* and *jet machining*;
- ❖ *electrochemical processes*: based on electrochemical energy to remove the material. Examples include *electrochemical machining*, and *electrochemical deburring* and *grinding*;
- ❖ *thermal energy processes*: use thermal energy generated by the conversion of electrical energy to shape or cut the workpiece. Examples include *electric discharge processes*, *electron beam machining*, *laser beam machining*, and *plasma arc cutting*;
- ❖ *chemical machining*: chemicals selectively remove material from portions of the workpiece, while other portions of the surface are mask protected.

## Ultrasonic Machining

Ultrasonic Machining is a non-traditional process, in which abrasives contained in a slurry are driven against the work by a tool oscillating at low amplitude (25-100  $\mu\text{m}$ ) and high frequency (15-30 KHz):

The process was first developed in 1950s and was originally used for finishing EDM surfaces.

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 between the tool and the work (gap is 25-40  $\mu\text{m}$ ) to provide abrasives and carry away chips. The majority of the cutting action comes from an ultrasonic (cyclic) force applied.



Ultrasonic machining.

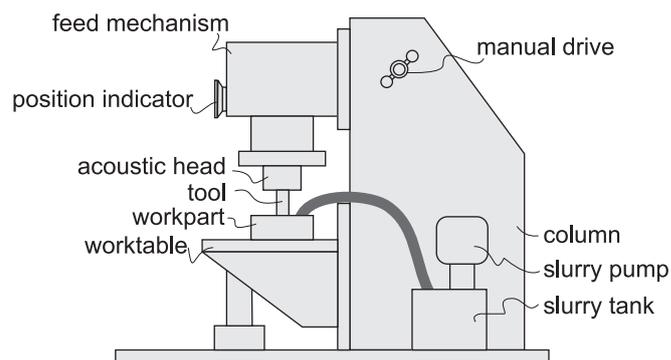
The basic components to the cutting action are believed to be,

- ❖ *brittle fracture* caused by impact of abrasive grains due to the tool vibration;
- ❖ *cavitation induced erosion*;
- ❖ *chemical erosion* caused by slurry.

The ultrasonic machining process can be used to cut through and blind holes of round or irregular cross-sections. The process is best suited to poorly conducting, hard and brittle materials like glass, ceramics, carbides, and semiconductors. There is a little production of heat and stress in the process, but work may chip at exit side of the hole. Sometimes glass is used on the backside for brittle materials. The critical parameters to control the process are the tool frequency, amplitude and material, abrasive grit size and material, feed force, slurry concentration and viscosity.

Limitations of the ultrasonic machining include very low material removal rate, extensive tool wear, small depth of holes and cavities.

Basic machine layout is shown in the figure,



Principal components of an ultrasonic machine.

The acoustic head is the most complicated part of the machine. It must provide a static constant force, as well as the high frequency vibration.

Tools are produced of tough but ductile metals such as soft steel or stainless steel. Aluminum and brass tools wear near 5 to 10 times faster.

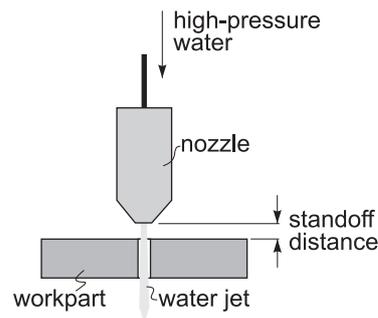
Abrasive slurry consists of a mixture of liquid (*water* is the most common but *oils* or *glycerol* are also used) and 20% to 60% of abrasives with typical grit sizes of 100 to 800. The common types of abrasive materials are *boron carbide*, *silicon carbide*, *diamond*, and *corundum* ( $\text{Al}_2\text{O}_3$ ).

## Jet Machining

In jet machining, high-velocity stream of water (*Water Jet Cutting*) or water mixed with abrasive materials (*Abrasive Water Jet Cutting*) is directed to the workpiece to cut the material. If a mixture of gas and abrasive particles is used, process is referred to as *Abrasive Jet Machining* and is used not to cut the work but for finishing operations like *deburring*, *cleaning*, *polishing*.

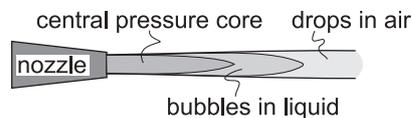
### Water Jet Cutting

*Water Jet Cutting* (WJC) uses a fine, high-pressure, high velocity (faster than speed of sound) stream of water directed at the work surface to cause slotting of the material:



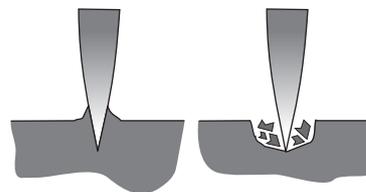
Water Jet Cutting.

Water is the most common fluid used, but additives such as alcohols, oil products and glycerol are added when they can be dissolved in water to improve the fluid characteristics. The fluid is pressurized at 150-1000 MPa to produce jet velocities of 540-1400 m/s. The fluid flow rate is typically from 0.5 to 2.5 l/min. The jet have a well behaved central region surrounded by a fine mist. The form of the exit jet is illustrated in the figure,



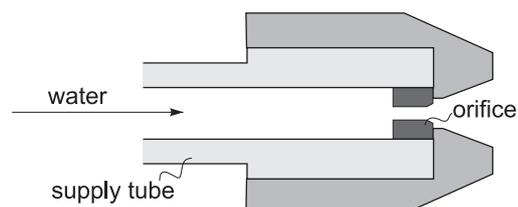
The jet structure in Water Jet Cutting.

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



Water Jet Cutting of ductile material (*Left*) and brittle materials (*Right*).

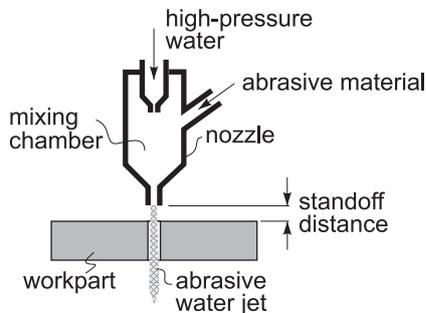
The typical nozzle head is shown below. The orifice is often made of sapphire and its diameter ranges from 1.2 mm to 0.5 mm:



The principle components of a nozzle head in Water Jet Cutting.

### Abrasive Water Jet Cutting (AWJC)

In *Abrasive Water Jet Cutting*, a narrow, focused, water jet is mixed with abrasive particles. This jet is sprayed with very high pressures resulting in high velocities that cut through all materials. The presence of abrasive particles in the water jet reduces cutting forces and enables cutting of thick and hard materials (steel plates over 80-mm thick can be cut). The velocity of the stream is up to 90 m/s, about 2.5 times the speed of sound.



Abrasive Water Jet Cutting.



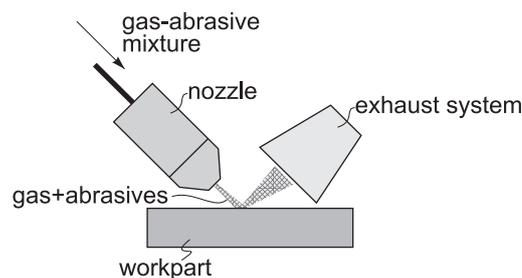
Abrasive Jet Cutter.

Abrasive Water Jet Cutting process was developed in 1960s to cut materials that cannot stand high temperatures for stress distortion or metallurgical reasons such as wood and composites, and traditionally difficult-to-cut materials, e.g. ceramics, glass, stones, titanium alloys.

The common types of abrasive materials used are *quartz sand*, *silicon carbide*, and *corundum* ( $\text{Al}_2\text{O}_3$ ), at grit sizes ranging between 60 and 120.

### Abrasive Jet Machining (AJM)

In *Abrasive Jet Machining*, fine abrasive particles (typically  $\sim 0.025\text{mm}$ ) are accelerated in a gas stream (commonly air) towards the work surface. As the particles impact the work surface, they cause small fractures, and the gas stream carries both the abrasive particles and the fractured (wear) particles away.



Abrasive Jet Machining.

The jet velocity is in the range of 150-300 m/s and pressure is from two to ten times atmospheric pressure.

The preferred abrasive materials involve *aluminum oxide* (*corundum*) and *silicon carbide* at small grit sizes. The grains should have sharp edges and should not be reused as the sharp edges are worn down and smaller particles can clog nozzle.

Abrasive Jet Machining is used for deburring, etching, and cleaning of hard and brittle metals, alloys, and nonmetallic materials (e.g., germanium, silicon, glass, ceramics, and mica).

## Electric discharge machining

In *electric discharge processes*, the work material is removed by a series of sparks that cause localized melting and evaporation of the material on the work surface.

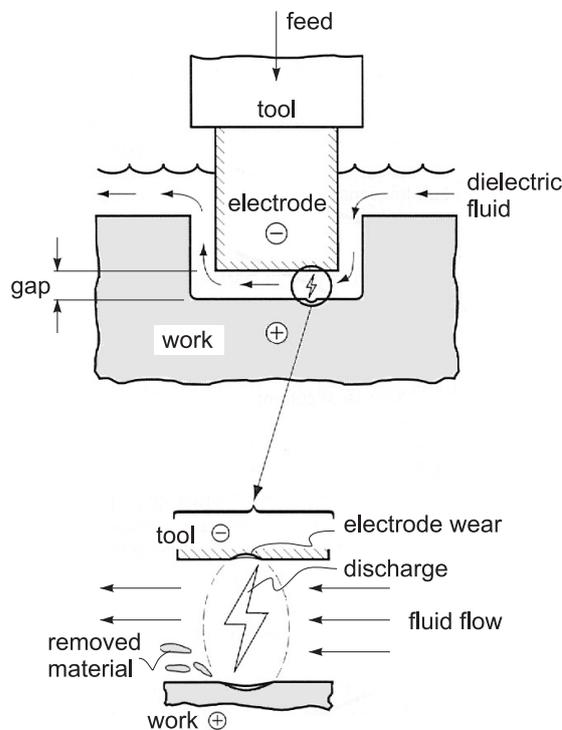
The two main processes in this category are

- ① *electric discharge machining*, and
- ② *wire electric discharge machining*.

These processes can be used only on electrically conducting work materials.

### Electric Discharge Machining

*Electric discharge machining* (EDM) is one of the most widely used nontraditional processes. An EDM setup and a close-up view of the gap between the tool and the work are illustrated in the figure:



The setup of Electric Discharge Machining (EDM) process and close-up view of gap, showing discharge and metal removal.



Electric Discharge Machine.

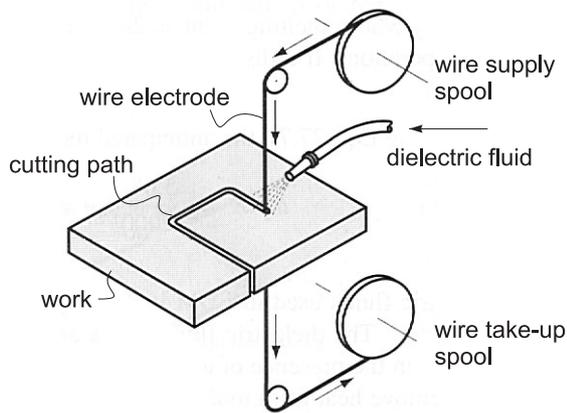
A formed electrode tool produces the shape of the finished work surface. The sparks occur across a small gap between tool and work surface. The EDM process must take place in the presence of a dielectric fluid, which creates a path for each discharge as the fluid becomes ionized in the gap. The fluid, quite often kerosene-based oil is also used to carry away debris. The discharges are generated by a pulsating direct-current power supply connected to the work and the tool.

Electrode materials are high temperature, but easy to machine, thus allowing easy manufacture of complex shapes. Typical electrode materials include copper, tungsten, and graphite.

The process is based on melting temperature, not hardness, so some very hard materials can be machined this way.

## Wire Electric Discharge Machining

*Wire Electric Discharge Machining* (Wire EDM) is a special form of EDM that uses a small diameter wire as the electrode to cut a narrow kerf in the work. Wire EDM is illustrated in the figure:



The setup of Wire Electric Discharge Machining (WEDM) process.

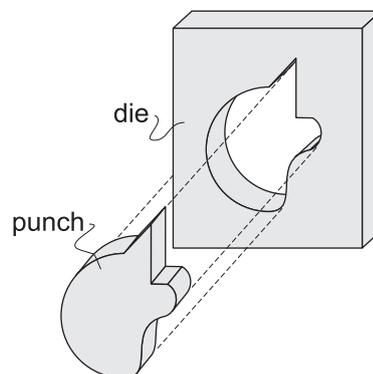


WEDM Machine.

The workpiece is fed continuously and slowly past the wire in order to achieve the desired cutting path. Numerical control is used to control the work-part motions during cutting. As it cuts, the wire is continuously advanced between a supply spool and a take-up spool to present a fresh electrode of constant diameter to the work. This helps to maintain a constant kerf width during cutting. As in EDM, wire EDM must be carried out in the presence of a dielectric. This is applied by nozzles directed at the tool-work interface as in the figure, or the workpart is submerged in a dielectric bath.

Wire diameters range from 0.08 to 0.30 mm, depending on required kerf width. Materials used for the wire include brass, copper, tungsten, and molybdenum. Dielectric fluids include deionized water or oil. As in EDM, an overcut in the range from 0.02 to 0.05 mm exists in wire EDM that makes the kerf larger than the wire diameter.

This process is well suited to production of dies for sheet metalworking, cams, etc. Since the kerf is so narrow, it is often possible to fabricate punch and die in a single cut, as illustrated in the figure:

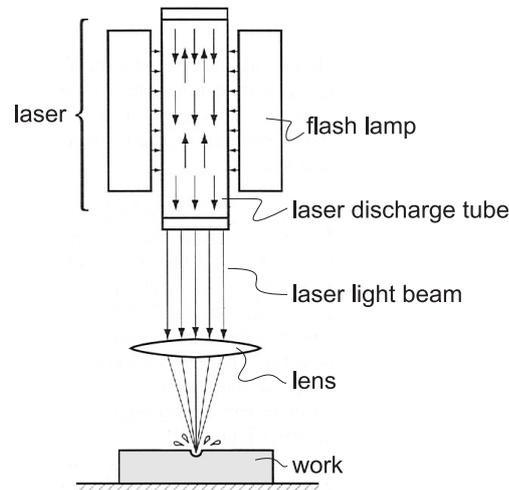


Punch and die fabricated in a single cut by WEDM.

## *Lasers and other beams*

### **Laser beam machining (LBM)**

Laser beam machining (LBM) uses the light energy from a laser to remove material by vaporization and ablation. The setup for LBM is illustrated in the figure:



The setup of laser beam machining process.

The types of lasers used in LBM are basically the carbon dioxide ( $\text{CO}_2$ ) gas lasers. Lasers produce collimated monochromatic light with constant wavelength. In the laser beam, all of the light rays are parallel, which allows the light not to diffuse quickly like normal light. The light produced by the laser has significantly less power than a normal white light, but it can be highly focused, thus delivering a significantly higher light intensity and respectively temperature in a very localized area.

Lasers are being used for a variety of industrial applications, including heat treatment, welding, and measurement, as well as a number of cutting operations such as drilling, slitting, slotting, and marking operations. Drilling small-diameter holes is possible, down to 0.025 mm. For larger holes, the laser beam is controlled to cut the outline of the hole.

The range of work materials that can be machined by LBM is virtually unlimited including metals with high hardness and strength, soft metals, ceramics, glass, plastics, rubber, cloth, and wood.

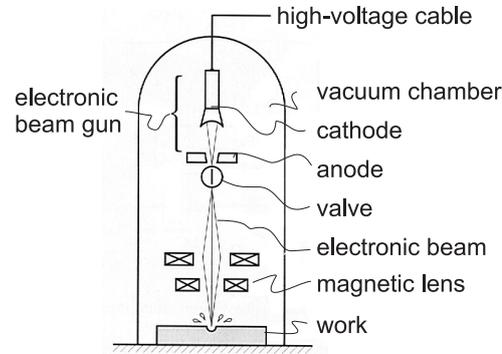
LBM can be used for 2D or 3D workspace. The LBM machines typically have a laser mounted, and the beam is directed to the end of the arm using mirrors. Mirrors are often cooled (water is common) because of high laser powers.



Laser cutting.

### Electron beam machining (EBM)

Electron beam machining (EBM) is one of several industrial processes that use electron beams. Electron beam machining uses a high-velocity stream of electrons focused on the workpiece surface to remove material by melting and vaporization. A schematic of the EBM process is illustrated in the figure:



The setup of electron beam machining process.

An electron beam gun generates a continuous stream of electrons that are focused through an electromagnetic lens on the work surface. The electrons are accelerated with voltages of approx. 150,000 V to create velocities over 200,000 km/s. The lens is capable of reducing the area of the beam to a diameter as small as 0.025 mm. On impinging the surface, the kinetic energy of the electrons is converted into thermal energy of extremely high density, which vaporizes the material in a very localized area. EBM must be carried out in a vacuum chamber to eliminate collision of the electrons with gas molecules.

Electron beam machining is used for a variety of high-precision cutting applications on any known material. Applications include drilling of extremely small diameter holes, down to 0.05 mm diameter, drilling of holes with very high depth-to-diameter ratios, more than 100:1, and cutting of slots that are only about 0.025 mm wide. Besides machining, other applications of the technology include heat treating and welding.

The process is generally limited to thin parts in the range from 0.2 to 6 mm thick. Other limitations of EBM are the need to perform the process in a vacuum, the high energy required, and the expensive equipment.