NON-CONVENTIONAL MACHINING METHODS

CONTENTS

ABSTRACT

The rapid developments in the field of materials has given an impetus to the modern manufacturing technology to develop, modify and is cover newer technological processes with a view to achieve results that are far beyond the scope of the existing conventional or traditional manufacturing processes. With the developments in the field of materials it has become essential to develop cutting tool materials and processes which can safely and conveniently machine such new materials for sustained productivity, high accuracy and versatility at automation. Consequently, non traditional techniques of machining are providing effective solutions to the problems imposed by the increasing demand for high strength temperature resistant alloys, the requirement of parts with intricate and compacted shapes and materials so hard as to defy machining by conventional methods. The processes are non traditional or non-conventional in the sense that they don’t employ a conventional or traditional tool for material removal, instead, they directly utilize some form of energy for metal machining.

Advance non conventional machining methods are following:-

I. Electro Chemical Machining
II. Abrasive Jet Machining
III. Electro Beam Machining
IV. Electro Discharge Machining
V. Laser Beam Machining

Chapter 1. INTRODUCTION

The development of harder & difficult ton machine metals & alloys such as tungsten, tantalum, beryllium, hast alloy, nitralloy, wasp alloy, nimonics, carbide, stainless steels and many other high strength temperature resistant (HSTR) alloys. These materials find wide application in aerospace, nuclear engineering and other industries going to their high strength to weight ratio, hardness and heat resisting qualities. The rapid developments in the field of materials has given an impetus to the modern manufacturing technology to develop, modify and is cover newer technological processes with a view to achieve results that are far beyond the scope of the existing conventional or traditional manufacturing processes. With the developments in the field of materials it has become essential to develop cutting tool materials and processes which can safely and conveniently machine such new materials for sustained productivity, high accuracy and versatility at automation. Consequently, non traditional techniques of machining are providing effective solutions to the problems imposed by the increasing demand for high strength temperature resistant alloys, the requirement of parts with intricate and compacted shapes and materials so hard as to defy machining by conventional methods. The processes are non traditional or non-conventional in the sense that they don’t employ a conventional or traditional tool for material removal, instead, they directly utilize some form of energy for metal machining. Conventional machining methods always produce some stress in the metal being cut. Newer methods have been developed that are essentially stress free. Very thin metals can be cut without distortion or stress.

The industries always face problems in manufacturing of components because of several reasons. This may be because of the complexity of the job profile or may be due to surface requirements with higher accuracy and surface finish or due to the strength of the materials. This challenge has been accepted and may new materials and unconventional methods of machining have been developed to suit the requirements of industry. The word unconventional means that the metals are such that they cannot be machined by conventional methods, but require some special techniques.

CLASSIFICATION OF ADVANCED MACHINING PROCESSES

MECHANICAL	THERMOELECTRIC	ELECTROCHEMICAL & CHEMICAL
• ABRASIVE JET MACHINING (AJM)	• PLASMA ARC MACHINING (PAM)	• ELECTROCHEMICAL MACHINING (ECM)
• ULTRASONIC MACHINING (USM)	• LASER BEAM MACHINING (LBM)	• CHEMICAL MACHINING (CHM)
• WATER JET MACHINING (WJM)	• ELECTRON BEAM MACHINING (EBM)	• BIOCHEMICAL MACHINING (BM)
• ABRASIVE WATER JET MACHINING (AWJM)	• ELECTRIC DISCHARGE MACHINING (EDM)	
• ABRASIVE FLOW MACHINING (AFM)		
• MAGNETIC ABRASIVE FINISHING (MAF)	• ION BEAM MACHINING (IBM)	

SOME HYBRID PROCESSES

↓

- ELECTRICAL DISCHARGE GRINDING (EDG)
- ELECTRICAL DISCHARGE ABRASIVE GRINDING (EDAG)
- ELECTROCHEMICAL GRINDING (ECG)
- ELECTROCHEMICAL SPARK MACHINING (ECSM)
- ULTRASONIC ASSISTED EDM

REMARKS

- ENHANCED VOLUMETRIC MATERIAL REMOVAL RATE
- COMPUTER CONTROL OF THE PROCESSES RESULTING IN BETTER PERFORMANCE
- APPLICATION OF ADAPTIVE CONTROL => UNMANNED MACHINING

I. ELECTRO CHEMICAL MACHINING

Electrochemical machining (ECM) is based on a controlled anodic electrochemical dissolution process of the workpiece (anode) with the tool (cathode) in an electrolytic cell, during an electrolysis process (Figure 1.1).

Electrolysis is the name given to the chemical process which occurs, for example, when an electric current is passed between two electrodes dipped into a liquid solution. A typical example is that of two copper wires connected to a source of direct current and immersed in a solution of copper sulfate in water as shown in Figure 1. 2.

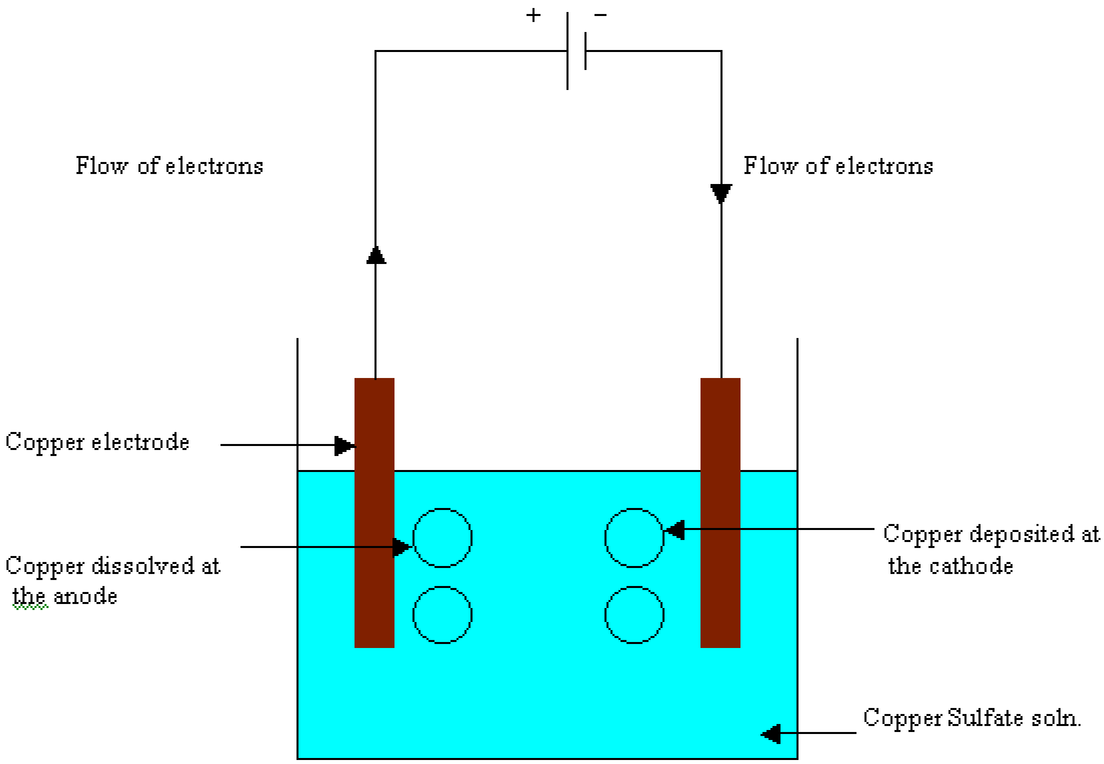


Figure 1.2. Electrochemical cell [1]

An ammeter, placed in the circuit, will register the flow of current. From this indication, the electric circuit can be determined to be complete. It is clear that copper sulfate solution obviously has the property that it can conduct electricity. Such a solution is termed as electrolyte. The wires are called electrodes, the one with positive polarity being the anode and the one with negative polarity the cathode. The system of electrodes and electrolyte is referred to as the electrolytic cell, while the chemical reactions which occur at the electrodes are called the anodic or cathodic reactions or processes.

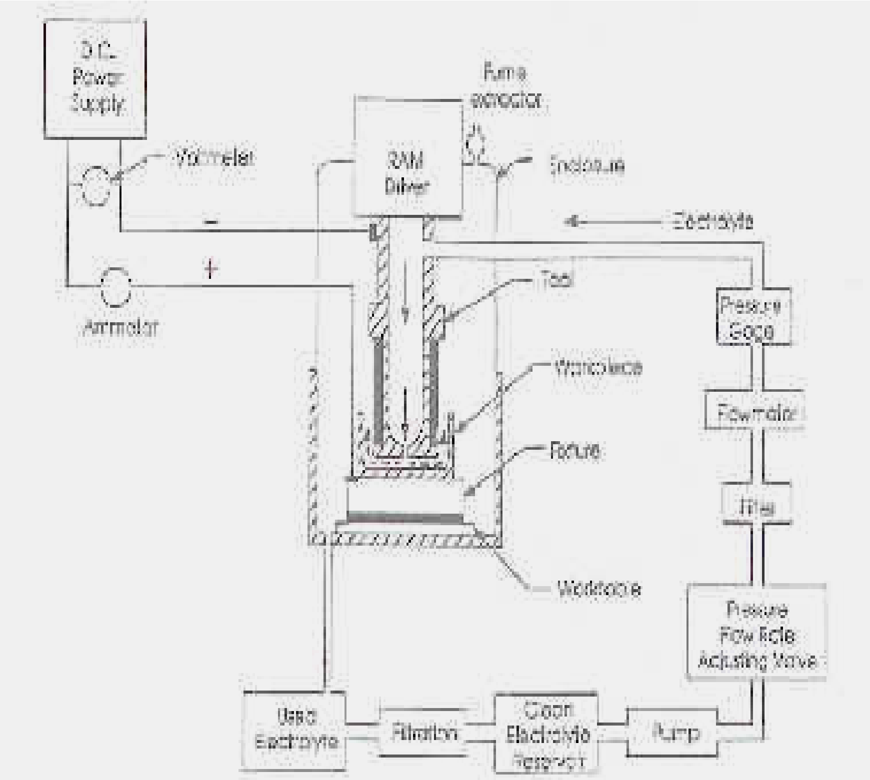
A typical application of electrolysis is the electroplating and electroforming processes in which metal coatings are deposited upon the surface of a cathode-workpiece. Current densities used are in the order of 10^{-2} to 10^{-1} A/cm^2 and thickness of the coatings is sometimes more than 1 mm.

An example of an anodic dissolution operation is electropolishing. Here the workpiece, which is to be polished, is made the anode in an electrolytic cell. Irregularities on its surface are dissolved preferentially so that, on their removal, the surface becomes smooth and polished. A typical current density in this operation would be 10^{-1} A/cm^2, and polishing is usually achieved on the removal of irregularities as small as 10 nm. With both electroplating and electropolishing, the electrolyte is either in motion at low velocities or unstirred.

A number of what we call compound methods have been developed in which ECM is ganged up with some other form of metal-working, for example, mechanical (as in abrasive ECM), erosion (electric discharge-electrochemical machining), ultrasonic, etc. Among other things, diamond EC grinding makes it possible to handle cemented-carbide plates, blade flanges and locks, outer and inner surfaces of parts made of magnetic alloys, and to grind cutting tools.

A typical Electrochemical machining system (Figure 1.11.) has four major subsystems:

- The machine itself
- The power supply
- The electrolyte circulation system
- The control system


D.C.
Power
Supply
Voltmeter
Ammeter
−
+
Fume
extractor
RAM
Driver
Enclosure
Electrolyte
Tool
Workpiece
Fixture
Worktable
Pressure
Gage
Flowmeter
Filter
Pressure
Flow Rate
Adjusting Valve
Used
Electrolyte
Filtration
Clean
Electrolyte
Reservoir
Pump

Typical values of parameters and conditions of ECM are presented

Power Supply

Type: Direct Current

Voltage: 5 to 30 V (continue or pulse)

Current: 50 to 40,000 A

Current Density: 10 to 500 A/cm^2 [65 to 3200 A/in^2]

Electrolyte

Type and Concentration

Most used:	NaCl at 60 to 240 g/l [½ to 2 lb/gal]
Frequently used:	$NaNO_3$ at 120 to 480 g/l [1 to 4 lb/gal]
Less Frequently used:	Proprietary Mixture
Temperature :	20 to 50^{o} C [68 to 122^{o}F]
Flow rate:	1 l/min/100A [0.264 gal/min/100A]
Velocity :	1500 to 3000 m/min [5000 to 10,000 fpm]
Inlet Pressure:	0.15 to 3 MPa [22 to 436 psi]
Outlet Pressure:	0.1 to 0.3 MPa [15 to 43.6

Frontal Working Gap :	0.05 to 0.3mm [0.002 to 0.012 in]
Feed rate:	0.1 to 20mm/min [0.004 to 0.7 in/min
Electrode material:	Brass,copper,bronze

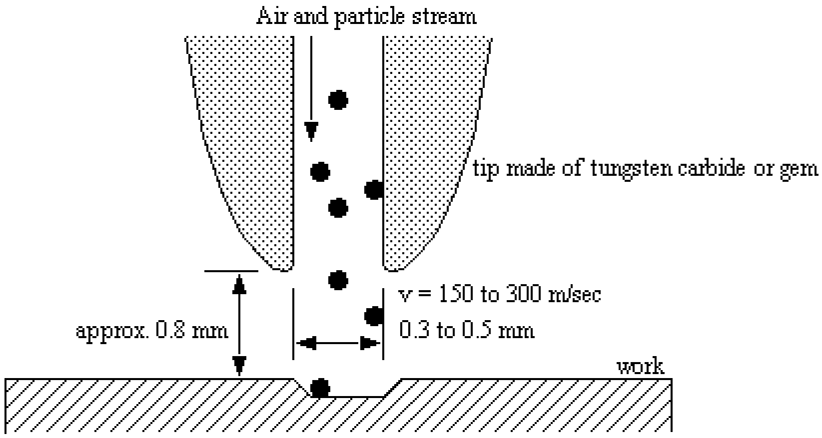
Tolerance

2-dimensional shapes:	0.05-0.2 mm [0.002- 0.008 in]
3-dimensioanl shapes:	0.1mm [0.004 in]
Surface Roughness (Ra)	0.1 to 2.5 μm [4 to 100 microinches]

II. ABRASIVE JET MACHINING (AJM)

· The physics,

1. 1. Fine particles (0.025mm) are accelerated in a gas stream (commonly air at a few times atmospheric pressure).
2. 2. The particles are directed towards the focus of machining (less than 1mm from the tip).
3. 3. As the particles impact the surface, they fracture off other particles.



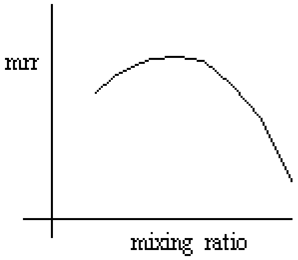
- As the particle impacts the surface, it causes a small fracture, and the gas stream carries both the abrasive particles and the fractured (wear) particles away.

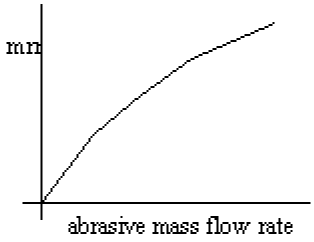
- Brittle and fragile work pieces work better.

- The factors are in turn effected by,
  1. - the abrasive: composition; strength; size; mass flow rate
  2. - the gas composition, pressure and velocity
  3. - the nozzle: geometry; material; distance to work; inclination to work

- The abrasive,
  1. - materials: aluminum oxide (preferred); silicon carbide
  2. - the grains should have sharp edges
  3. - material diameters of 10-50 micro m 15-20 is optimal
  4. - should not be reused as the sharp edges are worn down and smaller particles can clog nozzle.

- Gas jet,
  1. - mass flow rate of abrasive is proportional to gas pressure and gas flow
  2.

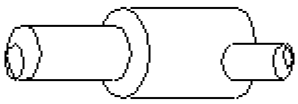


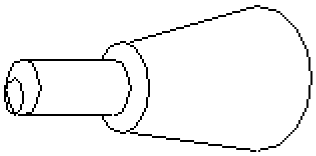


1. - pressure is typically 0.2 N/mm2 to 1N/mm2
2. - gas composition effects pressure flow relationship

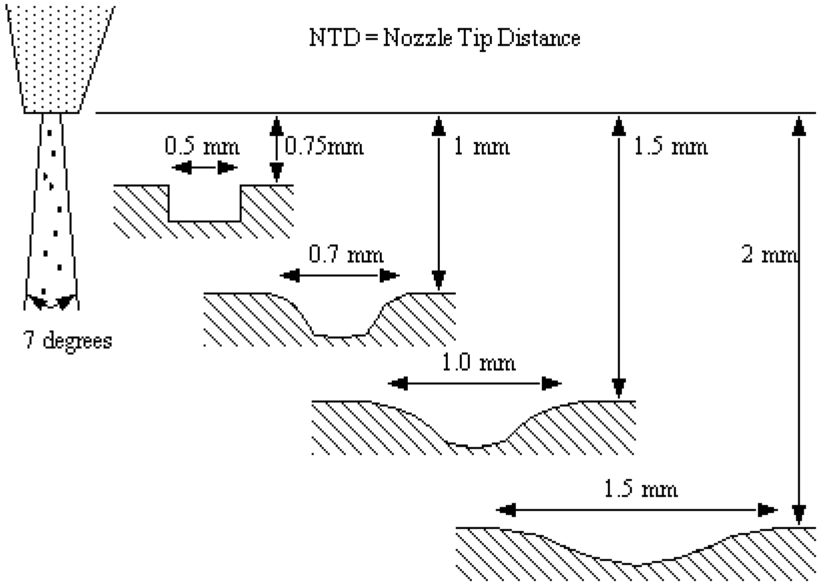
· Nozzle

1. - must be hard material to reduce wear by abrasives: WC (lasts 12 to 30 hr); sapphire (lasts 300 hr)
2. - cross sectional area of orifice is 0.05-0.2 mm2
3. - orifice can be round or rectangular
4. - head can be straight, or at a right angle


right angled head


straight head

· The relationship between head, and nozzle tip distance.



Summary of AJM characteristics

1. - Mechanics of material removal - brittle fracture by impinging abrasive grains at high speed
2. - media - Air, CO2
3. - abrasives: Al2O3, SiC, 0.025mm diameter, 2-20g/min, non-recirculating
4. - velocity = 150-300 m/sec
5. - pressure = 2 to 10 atm.
6. - nozzle - WC, sapphire, orifice area 0.05-0.2 mm2, life 12-300 hr., nozzle tip distance 0.25-75 mm
7. - critical parameters - abrasive flow rate and velocity, nozzle tip distance from work surface, abrasive grain size and jet inclination
8. - materials application - hard and brittle metals, alloys, and nonmetallic materials (e.g., germanium, silicon, glass, ceramics, and mica) Specially suitable for thin sections
9. - shape (job) application - drilling, cutting, deburring, etching, cleaning
10. - limitations - low metal removal rate (40 mg/min, 15 mm3/min), embedding of abrasive in workpiece, tapering of drilled holes, possibility of stray abrasive action.

III. ELECTRON BEAM MACHINING

- The basic physics is an electron beam is directed towards a work piece, the electron heat and vaporizes the metal.

- Typical applications are,
  1. - annealing
  2. - welding
  3. - metal removal

- Electrons accelerated with voltages of approx. 150,000V to create velocities over 200,000 km/sec.

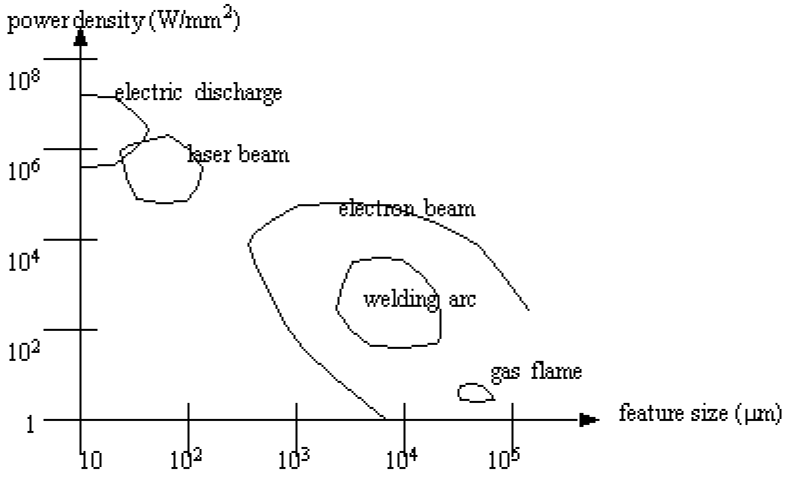
- Beam can be focused to 10 to 200 micro m and a density of 6500 GW/mm2

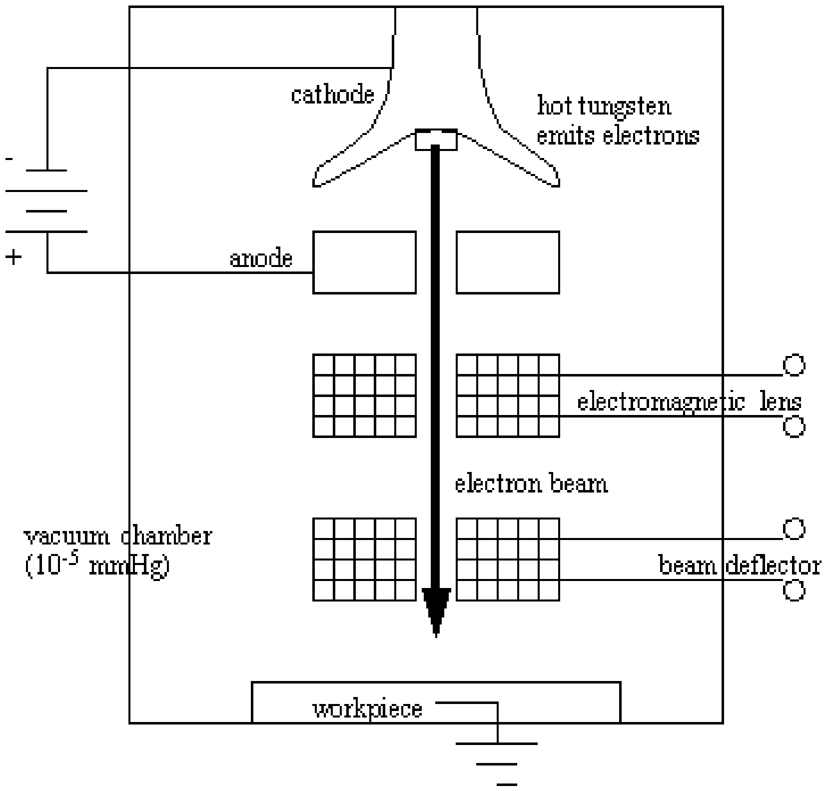
- Good for narrow holes and slots.
  1. e.g. a hole in a sheet 1.25 mm thick up to 125 micro m diameter can be cut almost instantly with a taper of 2 to 4 degrees

- The electron beam is aimed using magnets to deflect the stream of electrons

- A vacuum is used to minimize electron collision with air molecules.

- Beam is focused using an electromagnetic lens.


ASIDE: Power density available from different processes



Summary of EBM Characteristics

1. - Mechanics of material removal - melting, vaporization
2. - Medium - vacuum
3. - Tool - beam of electrons moving at very high velocity
4. - Maximum mrr = 10 mm3/min
5. - Specific power consumption = 450W/mm3/min
6. - Critical parameters - accelerating voltage, beam current, beam diameter, work speed, melting temperature
7. - Materials application - all materials
8. - Shape application - drilling fine holes, cutting contours in sheets, cutting narrow slots
9. - Limitations - very high specific energy consumption, necessity of vacuum, expensive machine.

ULTRA SONIC MACHINING

is achieved when the frequency of vibration matches with the *natural frequency* of tool and tool holder assembly.

The **tool shape** is made converse to the desired cavity. The tool is placed very near to the work surface, and the gap between the vibrating tool and the workpiece is flooded with abrasive slurry made up of fine abrasive particles and suspension medium (usually water). As the tool vibrates in its downward stroke, it strikes the abrasive particles. This impact from the tool propels the grains across the gap between the tool and the workpiece. These particles attain kinetic energy and strike the work surface with a force much higher than their own weight. This force is sufficient to remove material from the brittle workpiece surface and results in a crater on it. Each down stroke of the tool accelerates numerous abrasive particles resulting in the formation of thousands of tiny chips per second. A very small percentage (about 5 %) of material is also believed to be removed by a phenomenon known as **cavitation erosion**. To maintain a very low constant gap between the tool and the work, feed is usually given to the tool.

USM gives low **MRR** but it is capable to machine intricate cavities in single pass in fragile or /and hard materials. In USM, there is no direct contact between the tool and workpiece hence it is a good process for machining very thin and fragile components. A brittle material can be machined more easily than a ductile one. It is considered as a very safe process because it does not involve high voltage, chemicals, mechanical forces and heat.

ULTRASONIC MACHINING SYSTEM

USM machines are available in the range of **40 W to 2.4 kW**. USM system has sub-systems as power supply, transducer, tool holder, tool, and abrasives.

High power sine wave generator converts low frequency (60 Hz) electrical power to high frequency (≈20 kHz) electrical power. This high frequency electrical signal is transmitted to the transducer which converts it into high frequency low amplitude vibration. Essentially the transducer converts electrical energy to mechanical vibration. In USM, either of the two types of tranducers are used, i.e. piezoelectric or magnetostrictive type. **Piezoelectric crystals** (say, quartz) generate a small electric current when they are compressed. Also, when an electric current is passed through the crystal, it expands; when the current is removed the crystal attains its original size. This effect is know as piezoelectric effect. Such transducers are available up to a power capacity of 900 W.

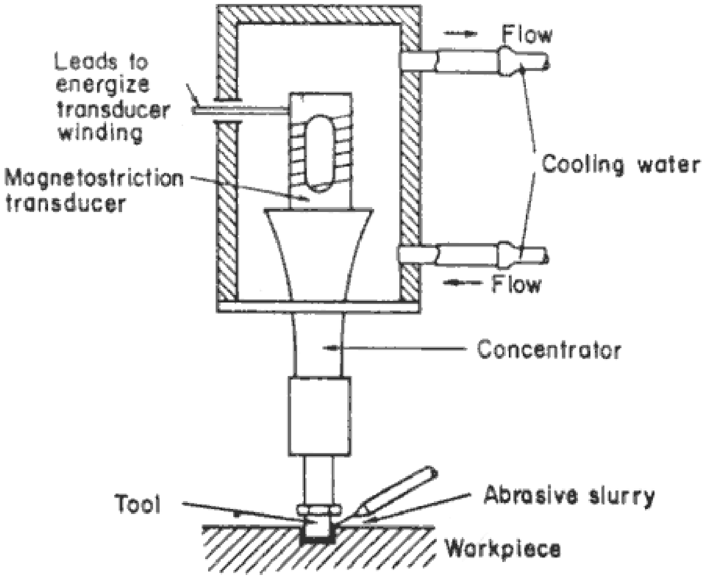


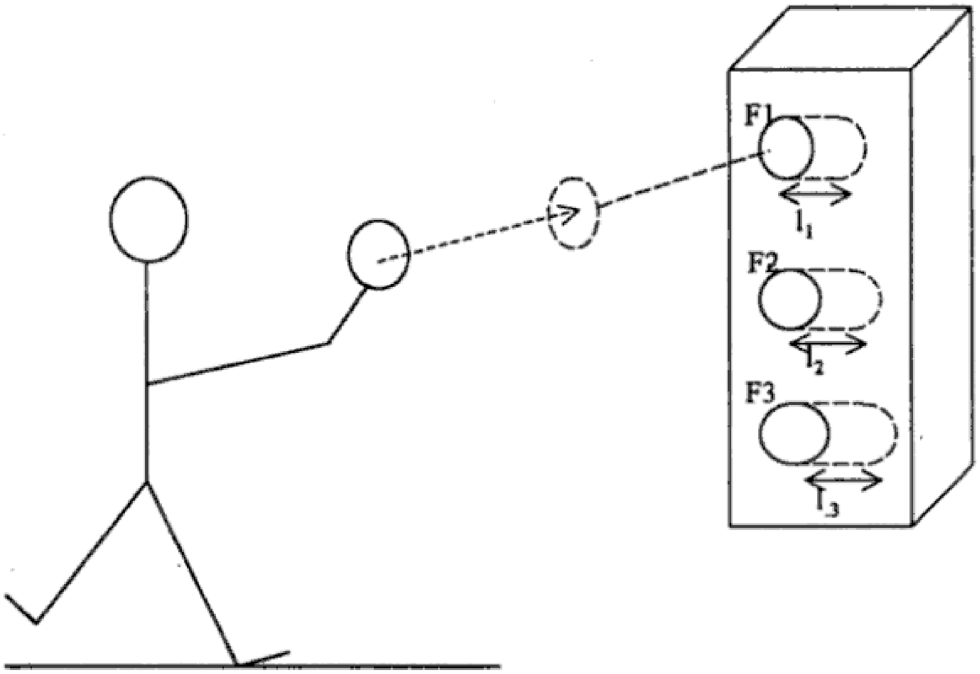
Fig. 3.2 A schematic diagram of ultrasonic machining [*Kaczmarck*, 1976].

In USM, the principle of **longitudinal magnetostriction** is used. When an object made of ferromagnetic material is placed in the continuously changing magnetic field, a change in its length takes place. The coefficient of magnetostrictive elongation (E_m) is defined as

$$E_m = \Delta L / L$$

where, ΔL is the change in length and L is the length of the magnetostrictor coil. This kind of transducer is known as **magnetostriction transducer**.

A device that converts any form of energy into ultrasonic waves is called **ultrasonic transducer**. In USM, a transducer converts high frequency electrical signal into high frequency linear mechanical motion (or vibration). These high frequency vibrations are transmitted to the tool via tool holder. For achieving optimum material removal rate (MRR), tool and tool holder are designed so that resonance can be achieved. *Resonance* (or maximum amplitude of vibration) ing force is contributed by the tool oscillating at ultrasonic frequency. The particles are of different sizes and they are thrown many times per second. In some cases, they are hammered also through the slurry. Fig. 3.2 shows a schematic diagram of USM system.

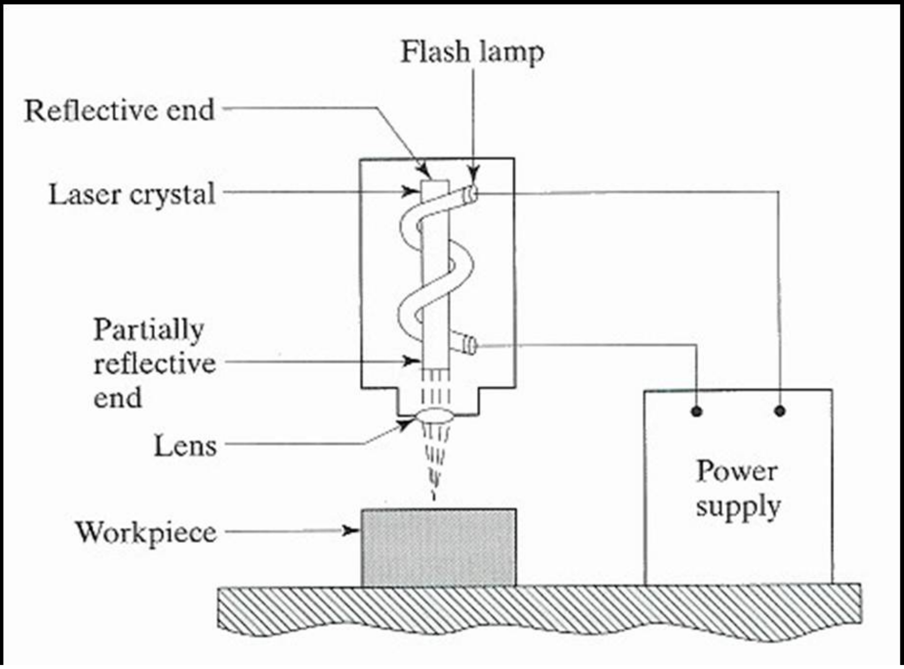


The word **ultrasonic** describes a vibratory wave having frequency larger than upper frequency limit of human ear (usually greater than 16 kc/s). Waves are usually classified as shear waves and longitudinal waves. High velocity longitudinal waves can easily propagate in solids, liquids and gases. They are normally used in ultrasonic applications.

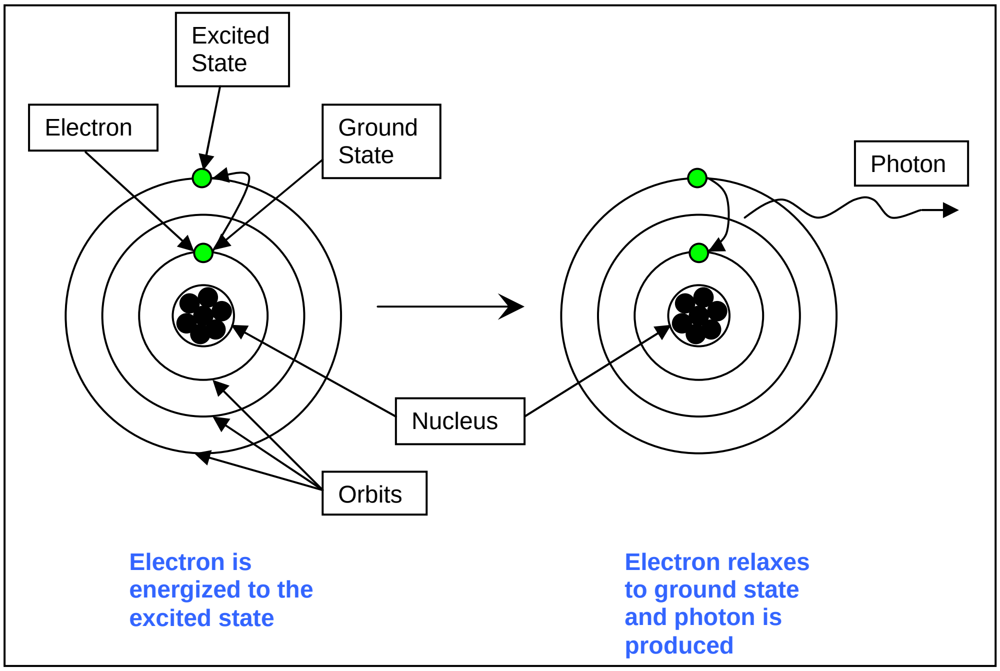
Laser Concept

- Add energy to make electrons “jump” to higher energy orbit
- Electron “relaxes” and moves to equilibrium at ground-state energy level
- Emits a photon in this process (key laser component)
- Two mirrors reflect the photons back and forth and “excite” more electrons
- One mirror is partially reflective to allow some light to pass through: creates narrow laser beam

Schematic of Laser Beam Machining Device



Photon Emission Model



Applications in Industry

- Manufacturing of metal sheets for truck bed hitch plates
- Splicing of aluminum sheets in the aircraft industry
- Cutting of Multi Layered Insulation for spacecraft

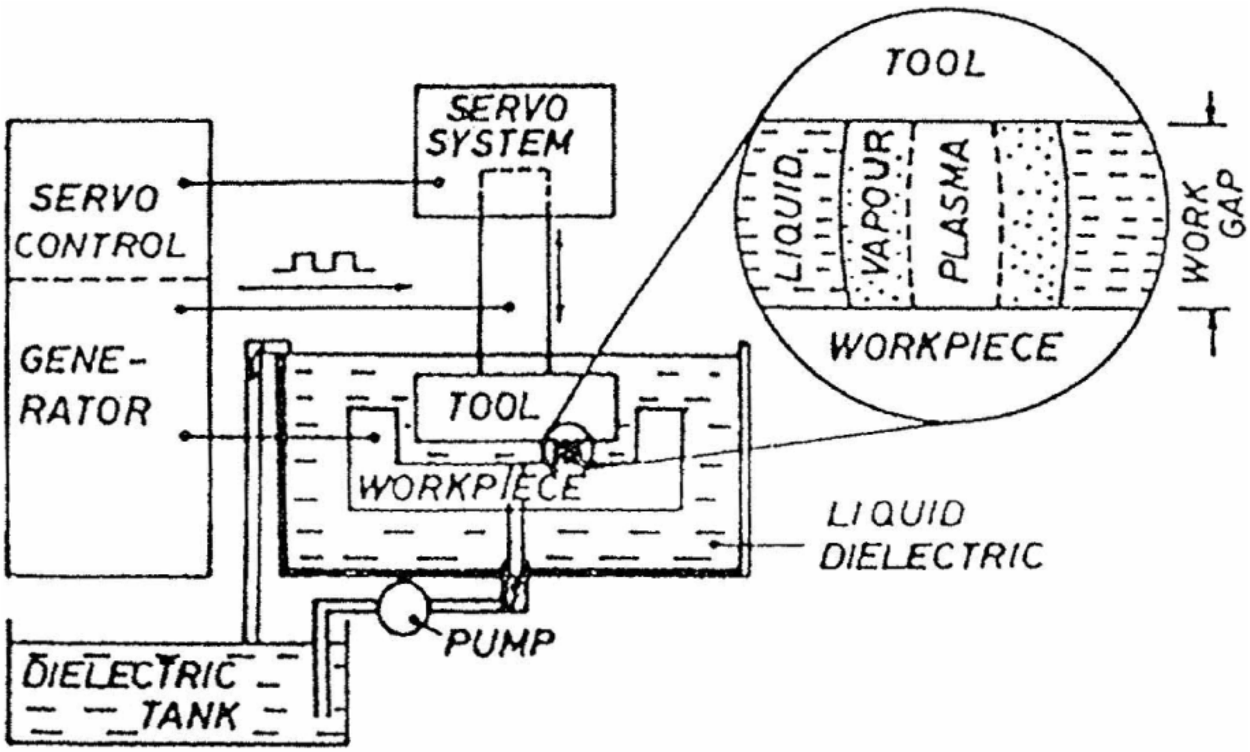
- More precise
- Useful with a variety of materials: metals, composites, plastics, and ceramics
- Smooth, clean cuts
- Faster process
- Decreased heat-affected zone

Conclusions

- “Brings science fiction to life”
- Enforces the concept of lasers in cutting various materials
- More smooth, precise, and clean cuts can be created
- Applications are abundant in a variety of fields

ELECTRO DISCHARGE MACHINING

Electro-discharge machining (EDM) is a widely used method for shaping conductive materials. EDM removes material by creating controlled sparks between a shaped electrode and an electrically conductive work piece. As part of the material is eroded, the electrode is slowly lowered into the work piece, until the resulting cavity has the inverse shape of the electrode. Dielectric fluid is flushed into the gap between the electrode andwork piece to remove small particles created by the process and to avoid excessive oxidation of the part surface and the electrode. The applications of EDM lie mainly in the tooling industry where it is applied on materials which are too hard to be machined with conventional techniques, such as milling or turning. The parts for these applications are usually larger than 1 mm, therefore conventional methods can be applied for fabricating the electrodes. Due to the fact that EDM can achieve very fine surface finishes, it has been trialed in the micromachining of conductive materials. For this purpose, copper electrodes obtained by LIGA (Lithographie Galvanoformung Abformung) have been used as die-sinking electrodes [1]. A related technique, wire electrodischarge grinding (WEDG), is also capable of fabricating parts with feature sizes below 100 _m [2, 3]. We dedicate thiswork to one of the pioneers of modern powder metallurgy, Claus G Goetzel, on the occasion of his 85th birthday. A few alternative methods exist for creating fine patterns in engineering materials. Wire EDM moves a fine wire, which is used as the electrode, through a sheet of part material and moves it along a programmed path. It can reach an excellent surface finish, however it is limited to parts with straight side walls. It cannot create blind holes, and requires highly accurate positioning equipment. Laser cutting (ablation) has been adapted for micromachining. Instead of electrical sparks, short laser pulses are used to selectively vaporize part material. This method does not require shaped electrodes, but, just like wire EDM, relies upon highly accurate actuators to move the laser over the part surface. The laser pulse rate is substantially lower than the spark pulse rate of micro-EDM machines, which makes the process much slower. The aim of this work is to show that the application of silicon micromachining in combination with EDM can extend the range of feasible sizes of parts manufactured with shape deposition manufacturing (SDM) [4, 5] by at least one order of magnitude into the mesoscopic range (with part or feature size between 100 _m and 1 mm). For most applications of SDM silicon itself is not a suitable material due to its low fracture toughness and poor electrical and magnetic properties. In order to be able to use engineering materials, silicon therefore serves as a mold for the following processing, in this case as mold for EDM electrodes.



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