Non-Traditional Machining
Introduction to Ultrasonic Machining

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Why USM

- One of the disadvantageous of EDM process was its application on conductive material.
- Ultrasonic Machining is a solution to machining of non-conductive material which was developed during the world war II.
- During this Covid-19 pandemic, it shows its benefit to weld polymeric material used in masks called ultrasonic welding.

History

- The roots of ultrasonic technology can be traced back to research on the piezoelectric effect conducted by Pierre Curie around 1880.

- He found that asymmetrical crystals such as quartz and Rochelle salt (potassium sodium titrate) generate an electric charge when mechanical pressure is applied. Conversely, mechanical vibrations are obtained by applying electrical oscillations to the same crystals.

- One of the first applications for Ultrasonic was sonar (an acronym for sound navigation ranging). It was employed on a large scale by the U.S. Navy during World War II to detect enemy submarines.

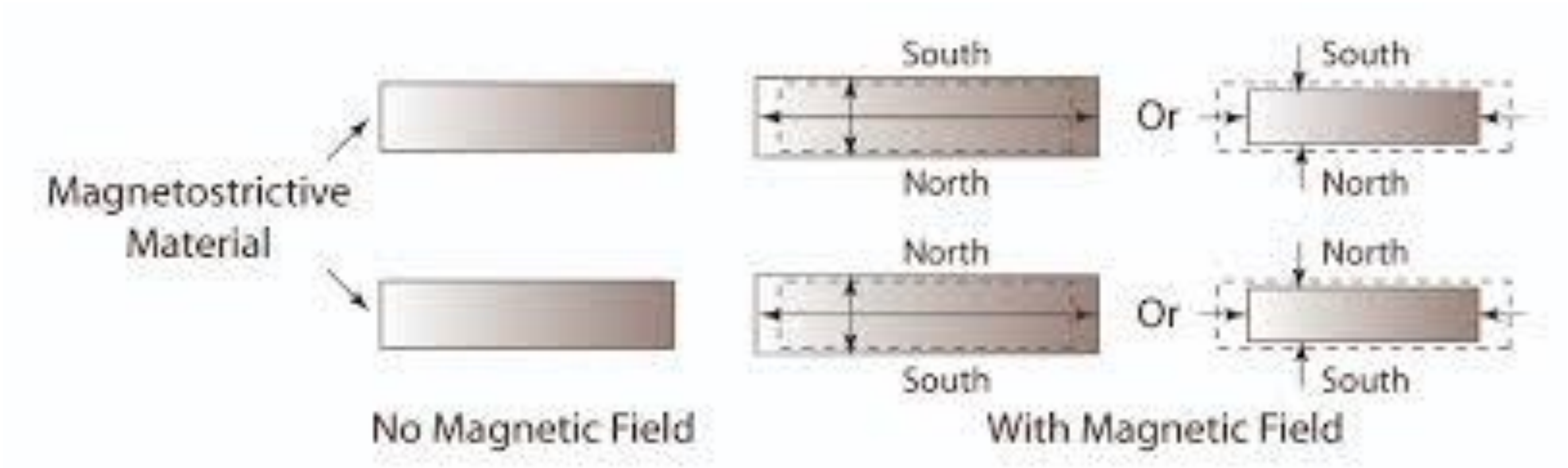
- Frequency values of up to 1Ghz (1 billion cycles per second) have been used in the ultrasonic industry.

- Today's Ultrasonic applications include medical imaging (scanning the unborn fetus) and testing for cracks in airplane construction.

Ultrasonic waves

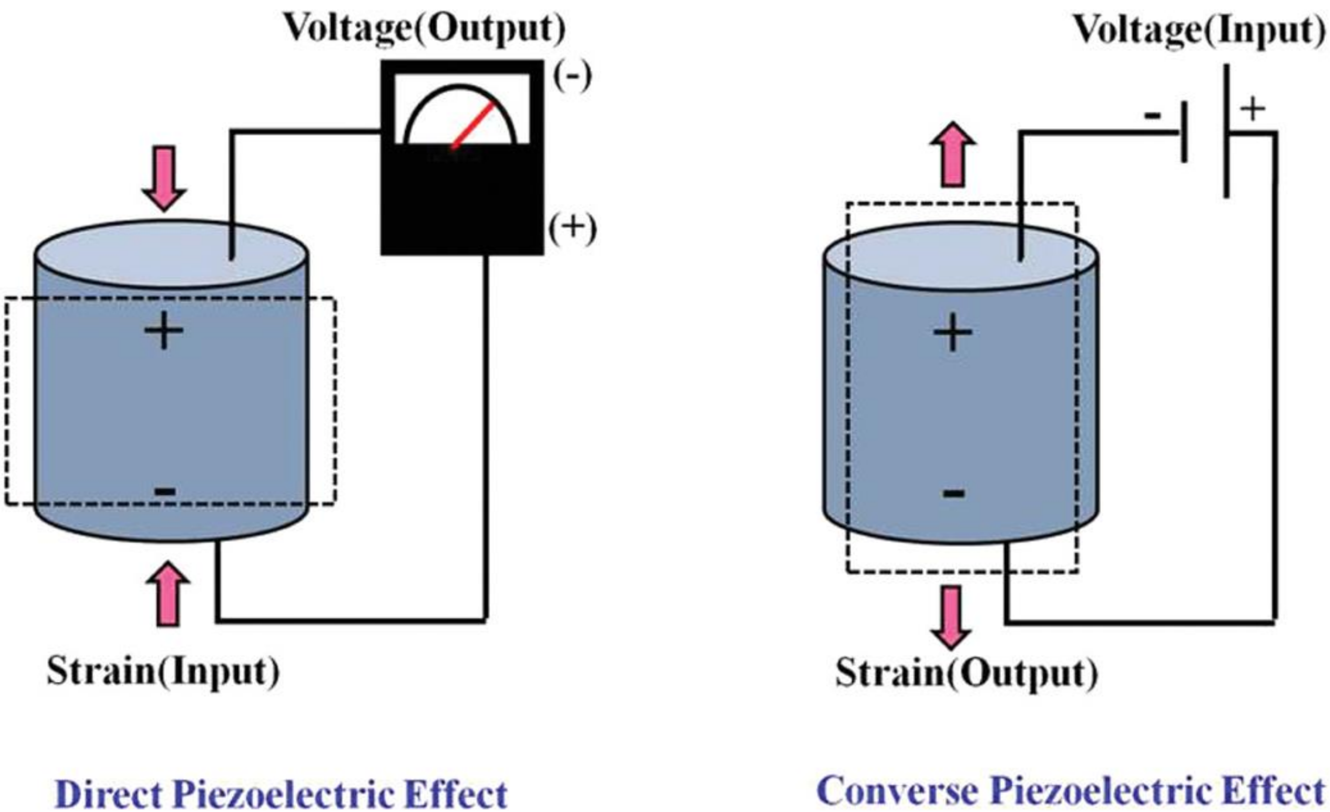
- The Ultrasonic waves are sound waves of frequency higher than 20,000 Hz (upper limit of human hearing).
- Ultrasonic waves can be generated using mechanical (piezoelectric effect) and electromagnetic (magnetostrictive effect) energy sources.
- They can be produced in gasses (including air), liquids and solids.

- Magnetostrictive transducers use the inverse magnetostrictive effect to convert magnetic energy into ultrasonic energy.
- This is accomplished by applying a strong alternating magnetic field to certain metals, alloys and ferrites.

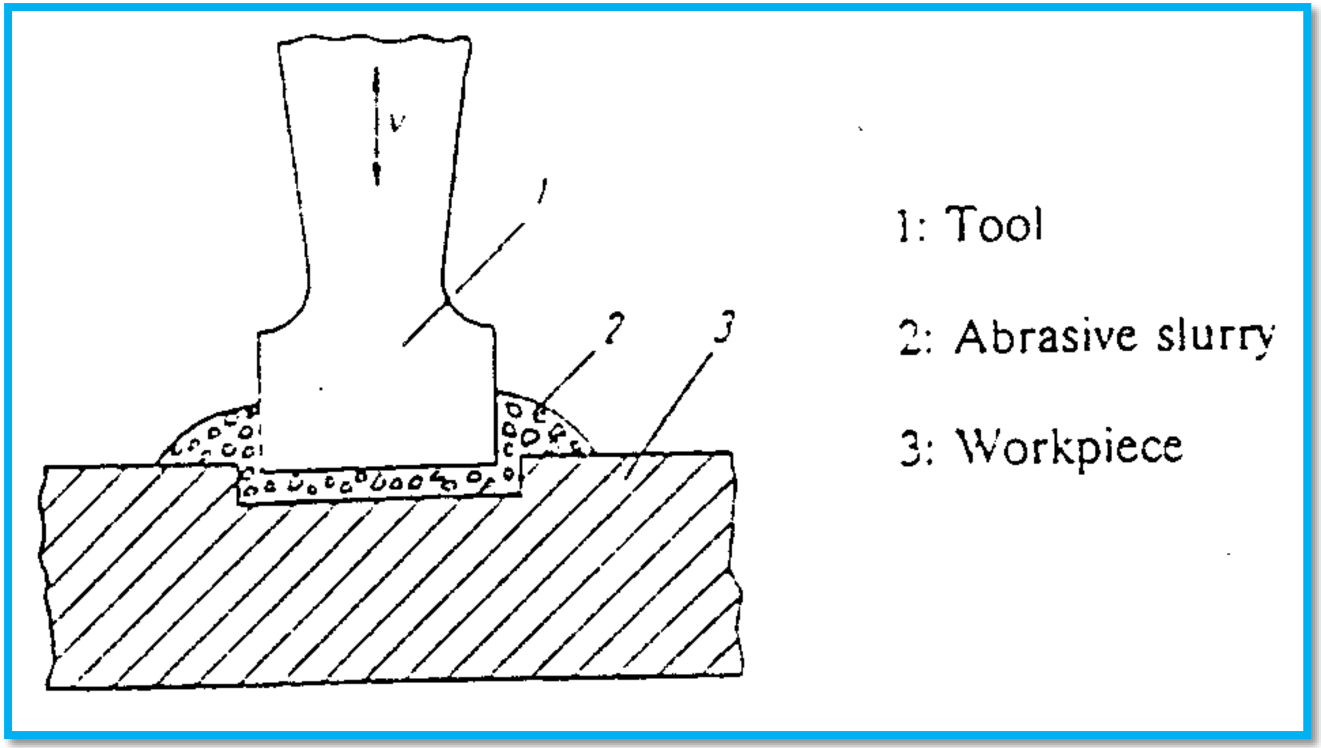


Ultrasonic waves: Piezoelectric Transducers

- Piezoelectric transducers employ the inverse piezoelectric effect using natural or synthetic single crystals (such as quartz) or ceramics (such as barium titanate) which have strong piezoelectric behavior.
- Mechanical vibrations are obtained by applying electrical oscillations to the crystals. Ceramics have the advantage over crystals in that they are easier to shape by casting, pressing and extruding.



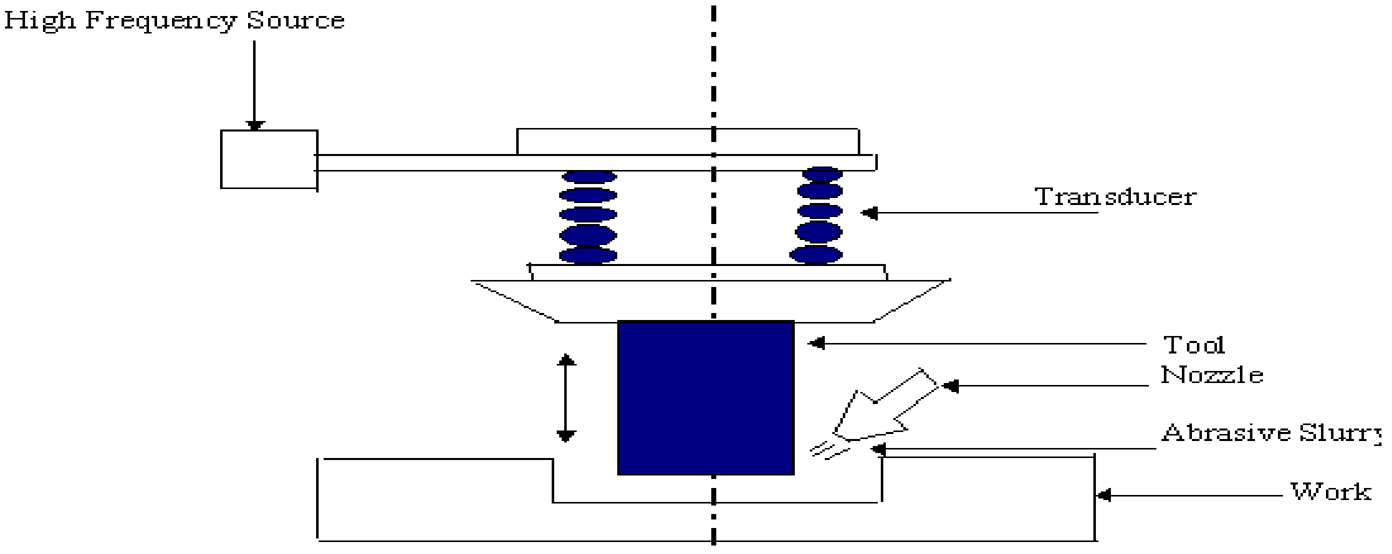
Principle of Ultrasonic Machining



In the process of Ultrasonic Machining, material is removed by micro-chipping or erosion with abrasive particles.

The tool forces the abrasive grits, in the gap between the tool and the workpiece, to impact normally and successively on the work surface, thereby machining the work surface.

Principle of Ultrasonic Machining



ULTRASONIC MACHINING

This is the standard mechanism used in most of the universal Ultrasonic machines

Principle of Ultrasonic Machining

- During one strike, the tool moves down from its most upper remote position with a starting speed at zero, then it speeds up to finally reach the maximum speed at the mean position.
- Then the tool slows down its speed and eventually reaches zero again at the lowest position.
- When the grit size is close to the mean position, the tool hits the grit with its full speed.
- The smaller the grit size, the lesser the momentum it receives from the tool.
- Therefore, there is an effective speed zone for the tool and, correspondingly there is an effective size range for the grits.

Principle of Ultrasonic Machining

- In the machining process, the tool, at some point, impacts on the largest grits, which are forced into the tool and workpiece.
- As the tool continues to move downwards, the force acting on these grits increases rapidly, therefore some of the grits may be fractured.
- As the tool moves further down, more grits with smaller sizes come in contact with the tool, the force acting on each grit becomes less.
- Eventually, the tool comes to the end of its strike, the number of grits under impact force from both the tool and the workpiece becomes maximum.
- Grits with size larger than the minimum gap will penetrate into the tool and work surface to different extents according to their diameters and the hardness of both surfaces.

USM System

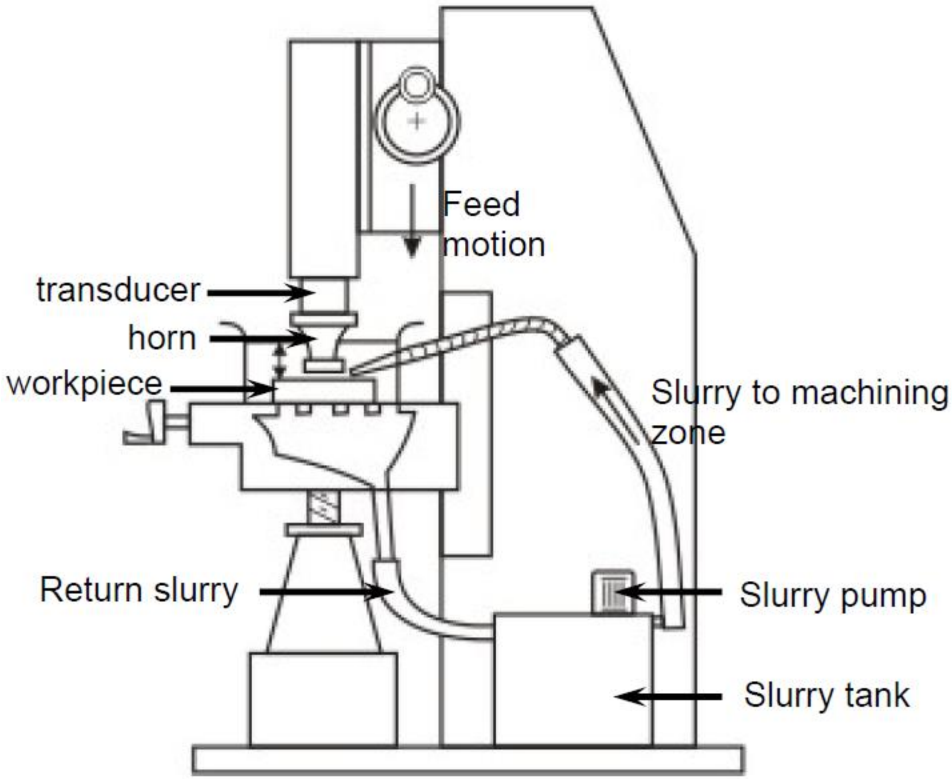
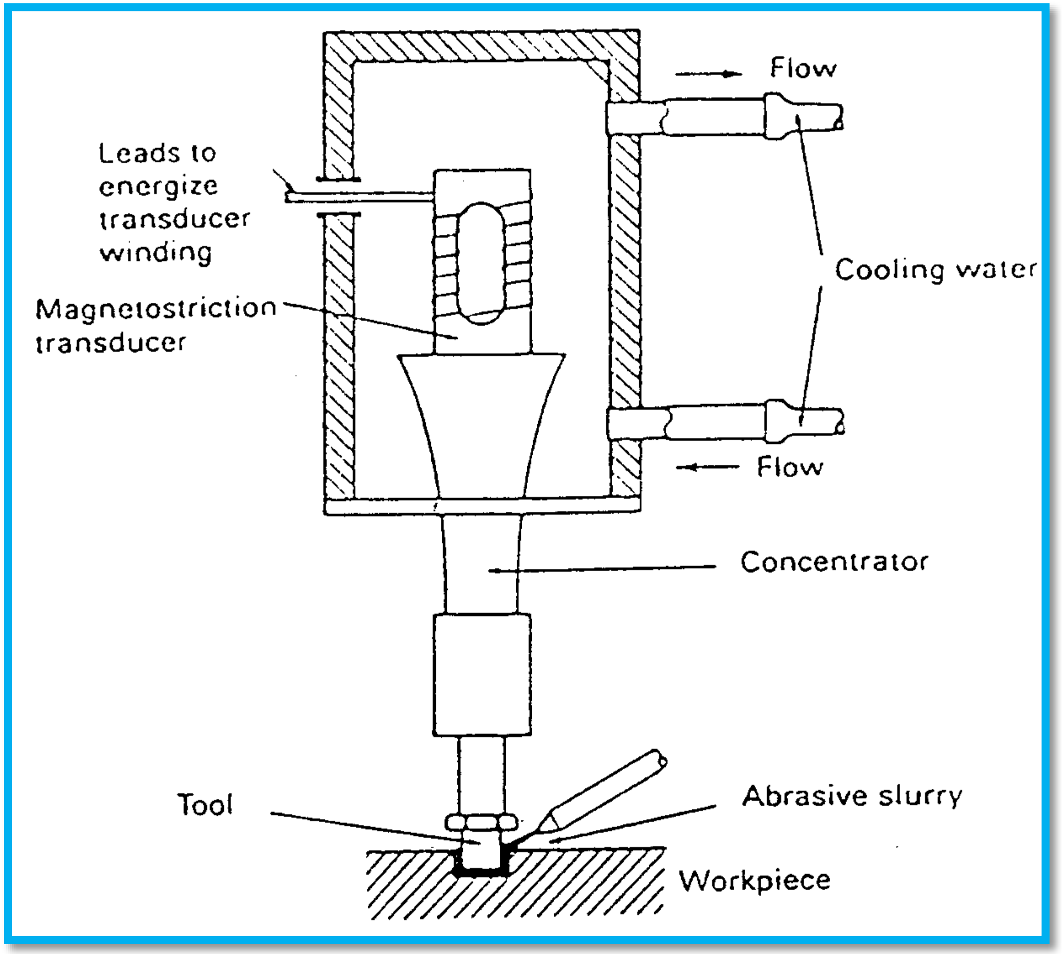


Fig1.Schematic view of an Ultrasonic Machine

- *Slurry delivery and return system .*
- *Feed mechanism to provide a downward feed force on the tool during machining.*
- *The transducer, which generates the ultrasonic vibration.*
- *The horn or concentrator, which mechanically amplifies the vibration to the required amplitude of 25 – 100 µm and accommodates the tool at its tip.*

USM System


Flow
Leads to energize transducer winding
Magnetostriction transducer
Cooling water
Flow
Concentrator
Tool
Abrasive slurry
Workpiece

Mechanism

Piezoelectric Transducer

- Piezoelectric transducers utilize crystals like quartz whose dimensions alter when being subjected to electrostatic fields.
- To obtain high amplitude vibrations, the length of the crystal must be matched to the frequency of the generator which produces resonant conditions.

$$\lambda = C.T = \frac{c}{f}$$

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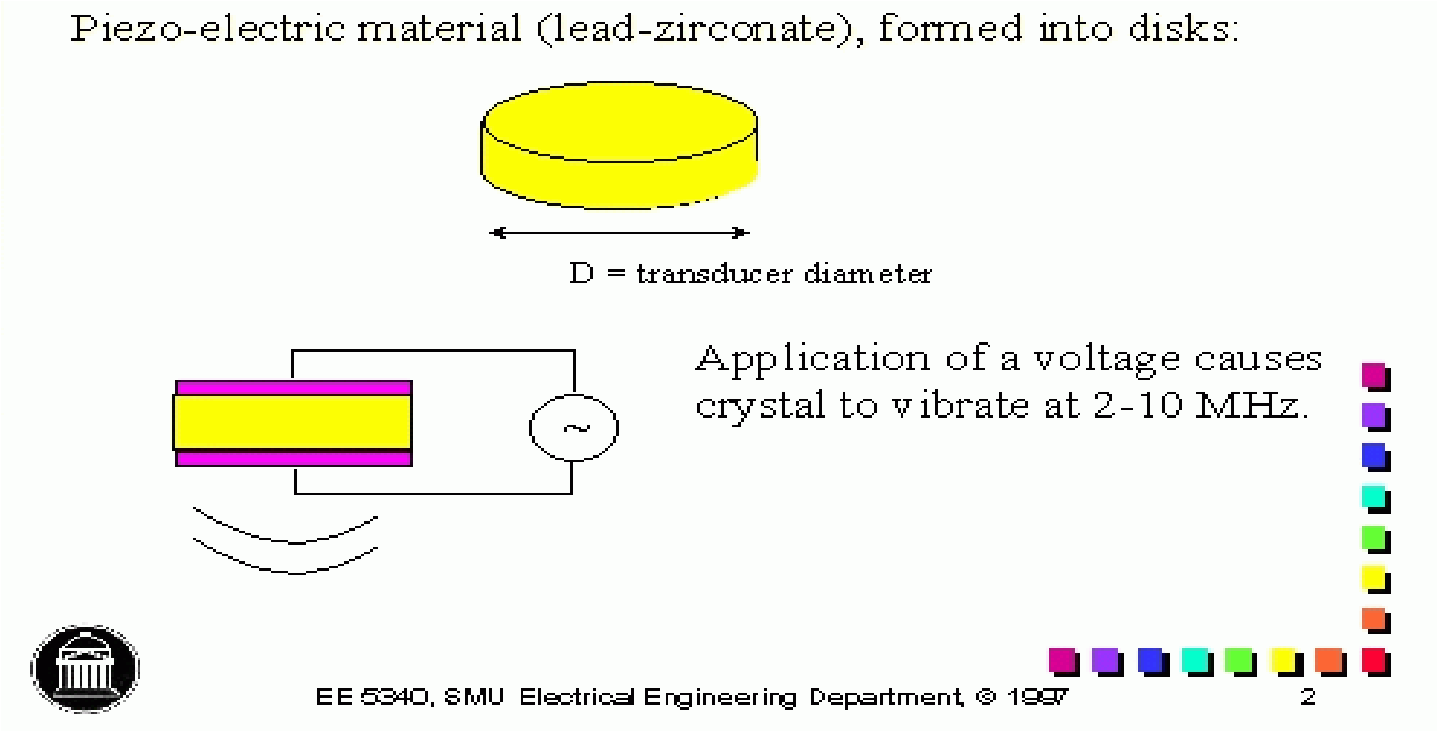
Mechanism

Piezoelectric Transducer

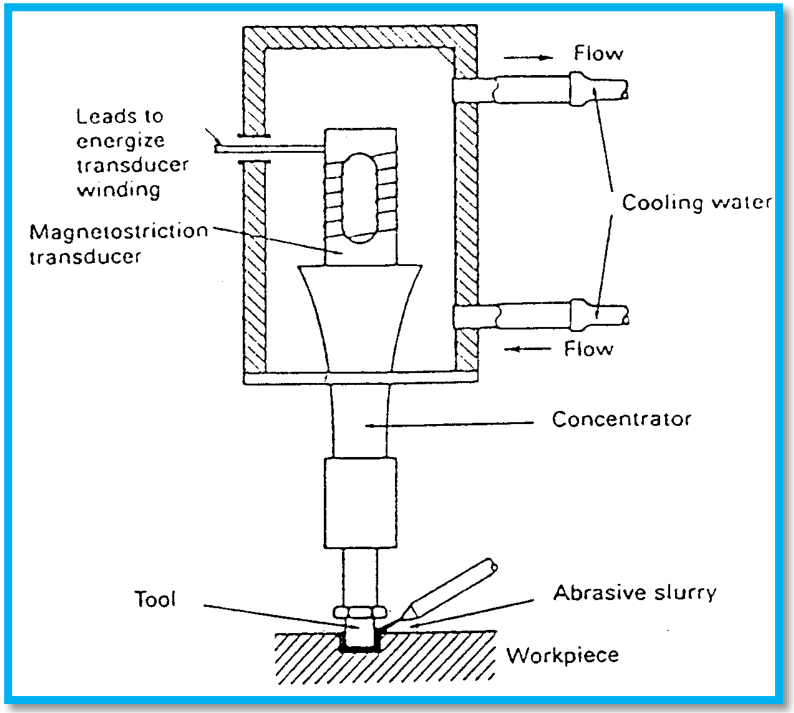


Mechanism

Magnetostrictive transducer

- Magnetostrictive transducers work on the principle that if a piece of Ferro-magnetic material (like nickel) is magnetized, then a change in dimension occurs.

- The transducer has solenoid type winding of wire over a stack of nickel laminations (which has rapid dimensional change when placed in magnetic fields) and is fed with an A.C supply with frequencies up to 25,000 c/s.



Mechanism

Tool holder (Concentrator)

- The shape of the tool holder is cylindrical or conical, or a modified cone which helps in magnifying the tool tip vibrations.

- In order to reduce the fatigue failures, it should be free from nicks, scratches and tool marks and polished smooth.

Mechanism

Tool

- Tool material should be tough and ductile. Aluminum and Titanium give good performance.
- Tools are usually 25 mm long ; its size is equal to the hole size minus twice the size of abrasives.
- Mass of tool should be minimum possible so that it does not absorb the ultrasonic energy.

Mechanism

Abrasive Slurry

- The abrasive slurry contains fine abrasive grains. The grains are usually boron carbide, aluminum oxide, or silicon carbide ranging in grain size from 100 for roughing to 1000 for finishing.
- It is used to microchip or erode the work piece surface and it is also used to carry debris away from the cutting area.

Materials that can be USMed

- Hard materials like stainless steel, glass, ceramics, carbide, quatz and semi-conductors are machined by this process.

- It has been efficiently applied to machine glass, ceramics, precision minerals stones, tungsten.

- Brittle materials

Applications

It is mainly used for

(1) drilling

(2) grinding

(3) Profiling

(4) Coining

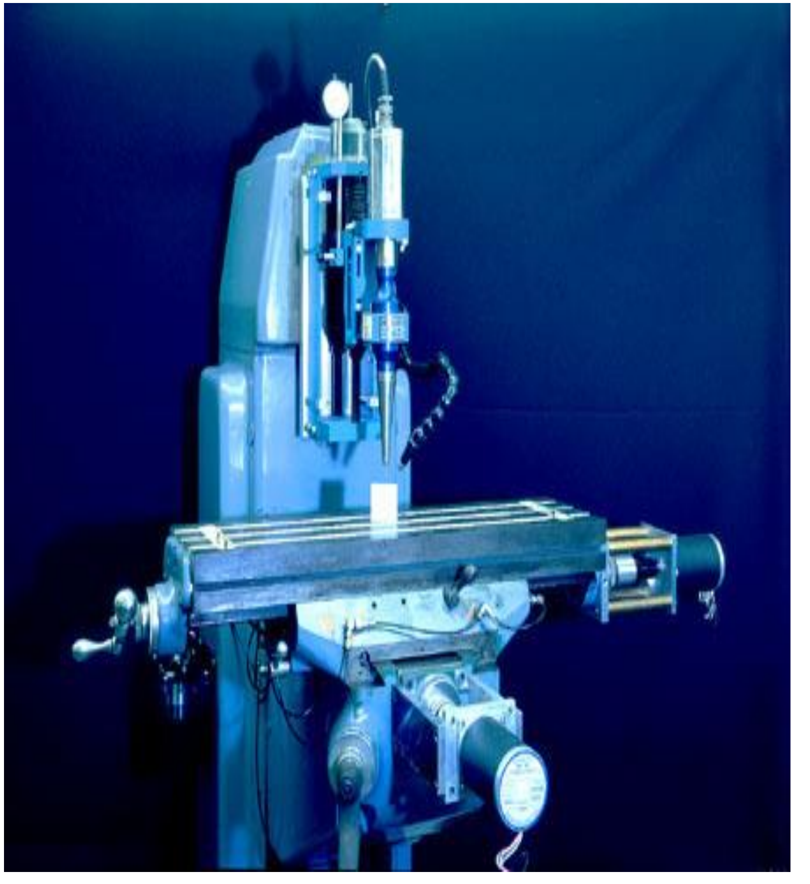
(5) piercing of dies

(6) welding operations on all materials which can be treated suitably by abrasives.

CNC Ultrasonic Machines

- 4-axis CNC drills holes as small as 0.010", multi-sided holes, multiple hole and slot patterns, and many other complicated, irregular shapes.

- Works on hard, brittle materials such as ceramic and glass with precision to 0.0005".



900 watt Sonic-mill, Ultrasonic Mill

Limitations

- Under ideal conditions, penetration rates of 5 mm/min can be obtained.
- Power units are usually 50-2000 watt output.
- Specific material removal rate on brittle materials is 0.018 mm cubic/Joule.
- Normal hole tolerances are ± 0.007 mm and a surface finish of 0.02 to 0.7 micro meters.

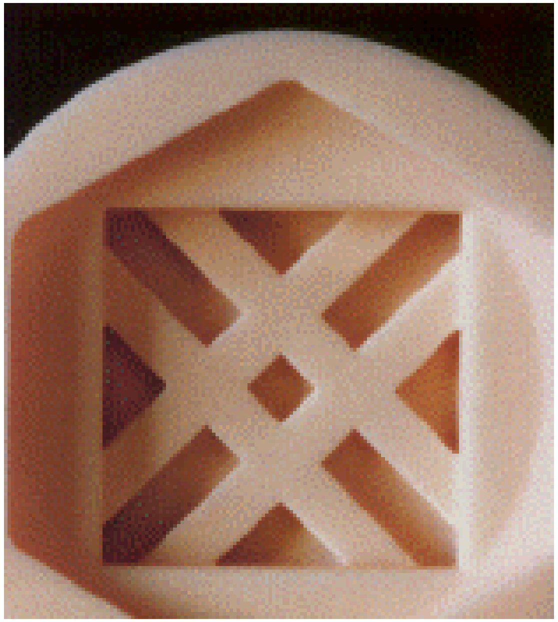
Advantages of USM

- Machining any materials regardless of their conductivity
- USM apply to machining semi-conductor such as silicon, germanium etc.
- USM is suitable to precise machining brittle material.
- USM does not produce electric, thermal, chemical abnormal surface.
- Can drill circular or non-circular holes in very hard materials
- Less stress because of its non-thermal characteristics

Disadvantages of USM

- USM has low material removal rate.
- Tool wears fast in USM.
- Machining area and depth is restraint in USM.

Various work samples machined by USM

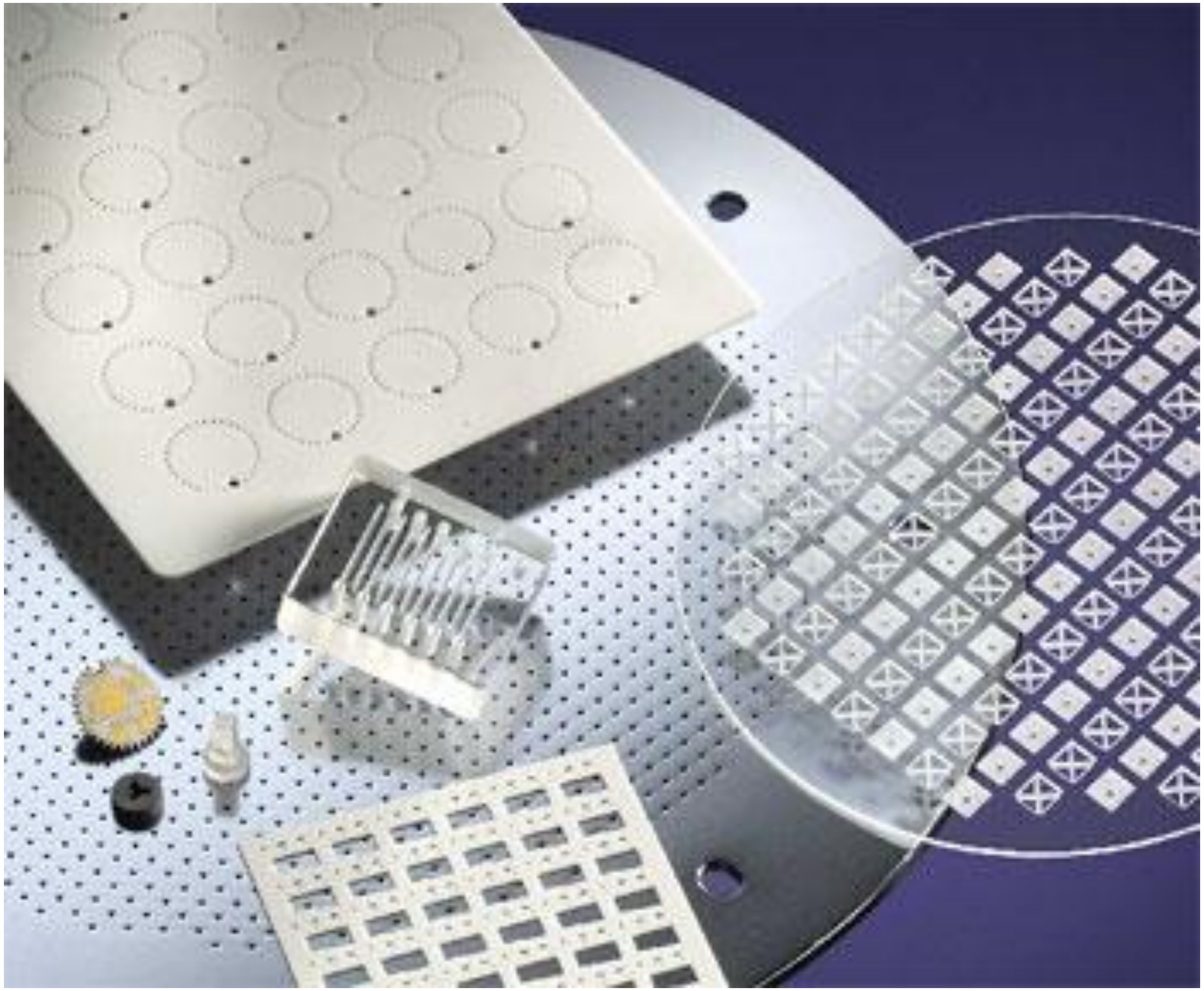


1- The first picture on the left is a plastic sample that has inner grooves that are machined using USM.

2- The Second picture (in the middle is a plastic sample that has complex details on the surface

3- The third picture is a coin with the grooving done by USM

Various work samples machined by USM



Safety Considerations

- The worker must be wearing eye goggles to prevent the abrasive particles or the microchips from getting into his/her eyes.

Questions???