Advanced Manufacturing Processes (AMPs)

Ultrasonic Machining (USM)

by
Dr. Sunil Pathak
Faculty of Engineering Technology
sunilpathak@ump.edu.my

Chapter Description

- Aims
  - To provide and insight on advanced manufacturing processes
  - To provide details on why we need AMP and its characteristics
- Expected Outcomes
  - Learner will be able to know about AMPs
  - Learner will be able to identify role of AMPs in todays sceneries
- Other related Information
  - Student must have some basic idea of conventional manufacturing and machining
  - Student must have some fundamentals on materials
- References
  - ……..
  - ……..
  - ……..

ULTRASONIC MACHINING (USM)

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

INTRODUCTION

- 1927 – Wood and Loomis proposed the use of ultrasound for machining.
- Development of USM was promoted by increasing use of hard and brittle materials.
- 1951 – First report on equipment and technology of USM.
- 1954 – Manufacture or USM machine tools.
- Initial application of USM – finishing process for EDM.
- USM became important again in the era of solid state electronic – to machine non-conductors, semi-conductors and brittle materials.
- USM can machine either **conducting** or **non-conducting** materials.
- Examples of **materials** that can be machined include glass, diamond, ceramics, carbides, stainless steel, silicon nitride, ruby, sapphire, etc.

USES OF ULTRASONIC VIBRATION

- Ultrasonic cleaning; watch, jewellery, electronics, motor bike factory
- Ultrasonic welding; magnetic tape spools, metal insertion into plastics (eg. wiring of PCB terminal). Application: dissimilar materials (eg. dissimilar plastics, plastic to metal). Advantages: consistency, strong.
- Ultrasonic seam welding
- Non destructive testing; crack detection of welds, etc, high speed testing, non-contact testing
- Ultrasonic machining; for hard and brittle materials

Marketing Motto from Sonic-Mill company catalogue

SONIC-MILL®

a member of THE BELL GROUP

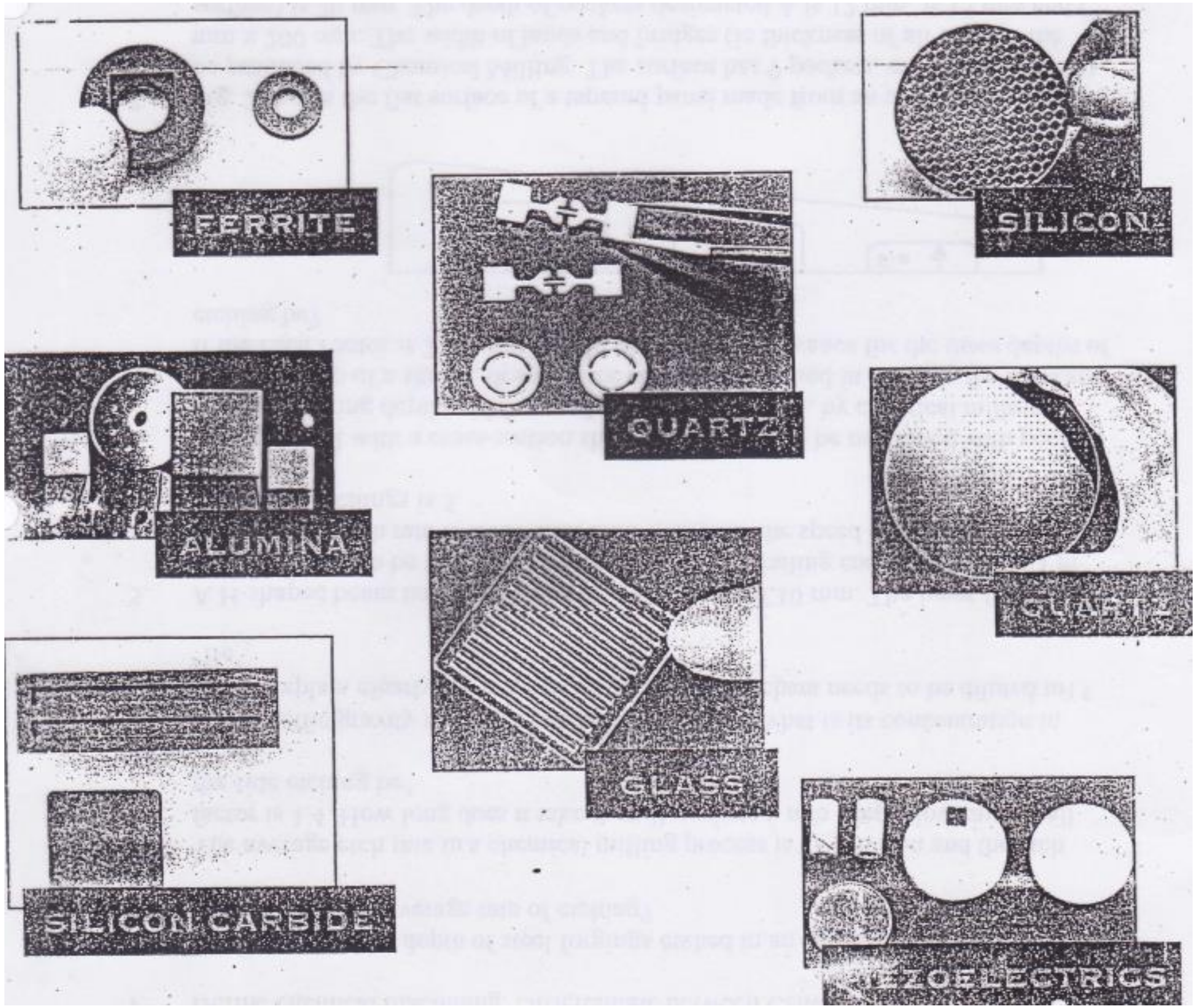
7500 Bluewater Rd. NW
Albuquerque, NM 87121-1962 USA
Phone (505) 839-3535
Fax (505) 839-3525
e-mail 102150.02453@compuserve.com
www.ceramics.com/sonic

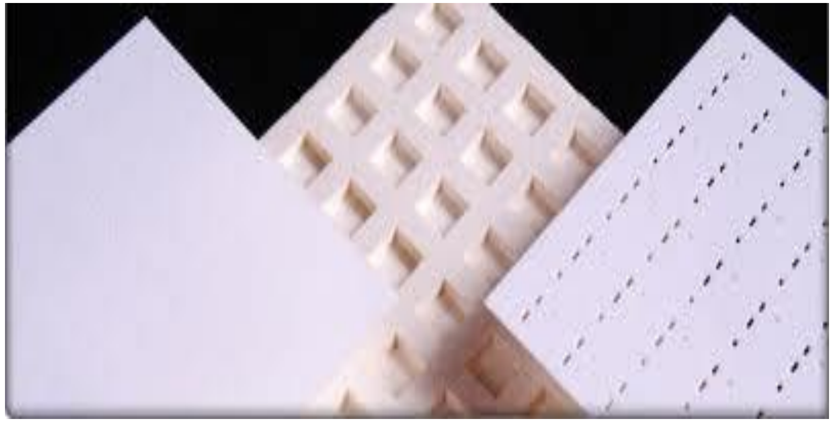
SONIC-MILL® Processing Equipment

for the machining of . . . .

THE "UN-MACHINABLE"

For the machining of …… the "un-machinable"





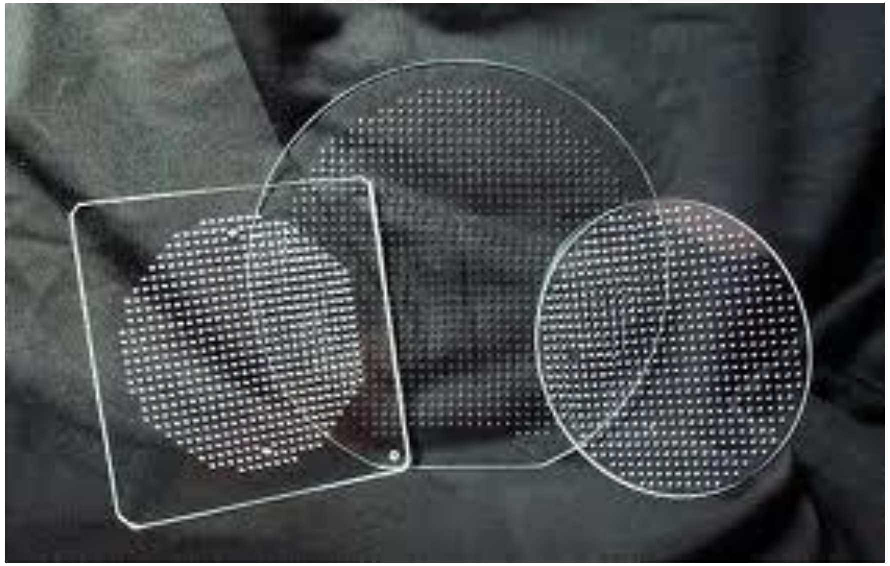


Figure: Ceramics

Figure: Holes in glass by USM [J Anderson]

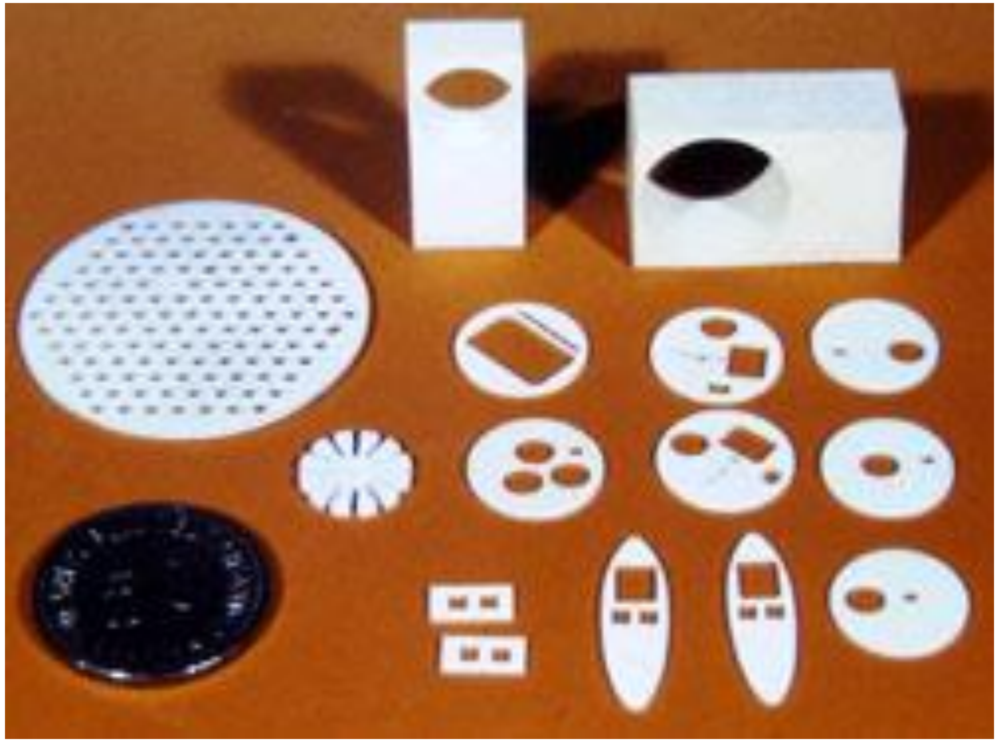
Examples of products using USM

Material: zircon oxide.

Machining purposes: determination of machining values. The test serves to determine the machinability of the material and to check formation of micro-cracks. It turned out that, according to the technical data, the material is readily machinable; no formation of micro-cracks.

Machining time: hollow tools of different diameters, between 2 mm and 22 mm, were used. Approx. 12-15 minutes are necessary to drill a hole of 25 mm depth. With regard to small and large drillings, there is no significant difference in time, since a small diameter tool can only be operated at low energy

Examples of products using USM



Shaped parts of Al2O3 Alumina.
This material is mainly used to produce samples of plate or bar-shaped semi-finished products machined with self-made tools.

ULTRASONIC MACHINING (USM)

WORKING PRINCIPLES

Material is removed through **impingement** of **abrasive** particles which are impacted onto the work surface by a **tool which vibrates** at a high frequency. The abrasive particles are suspended in a **liquid** in a form of slurry. The shape machined depends on the shape of the tool used.

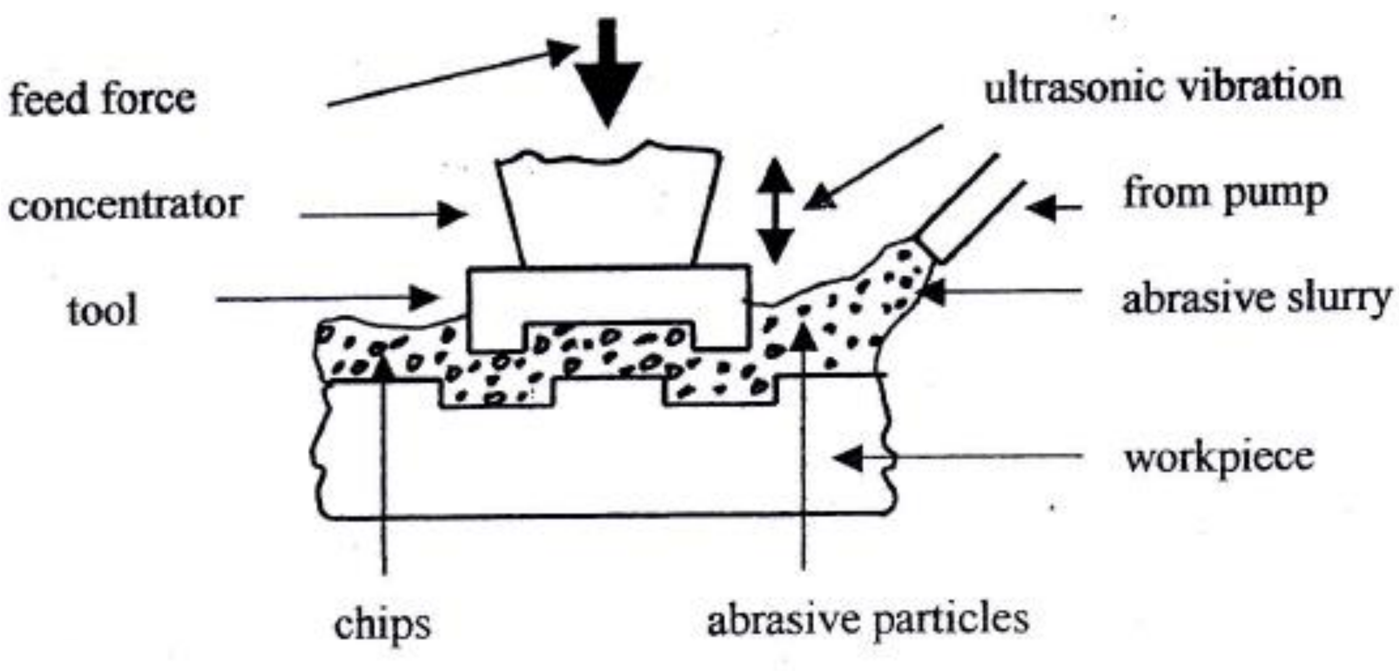
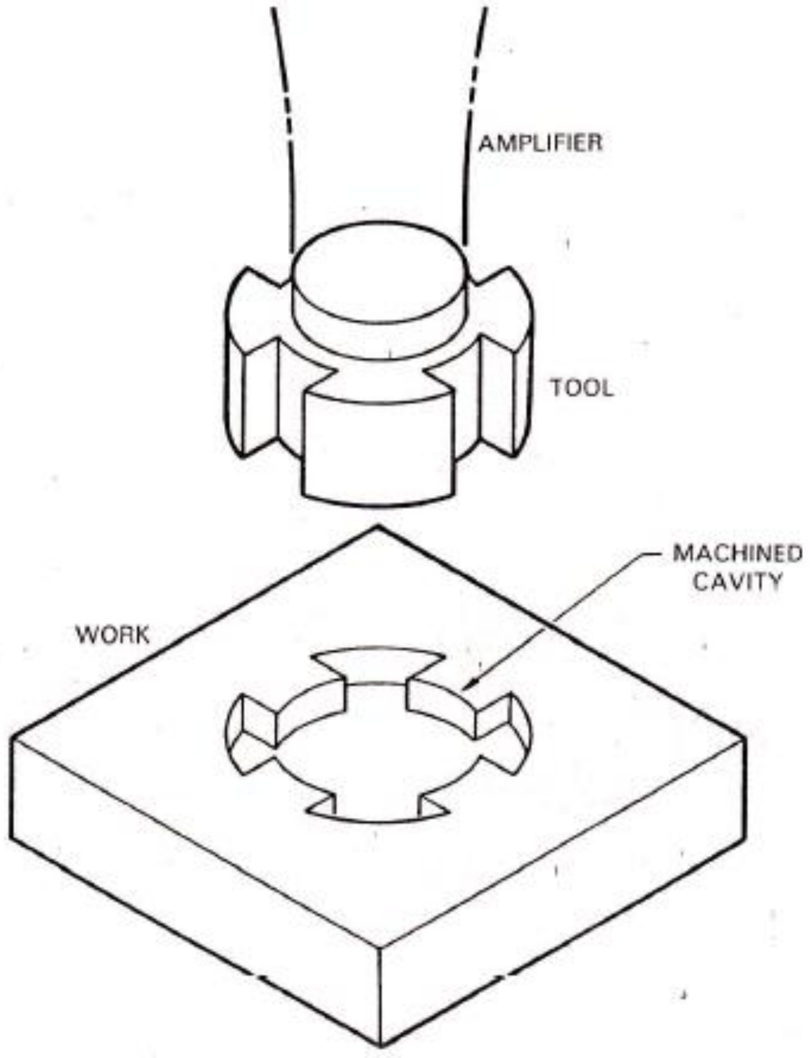
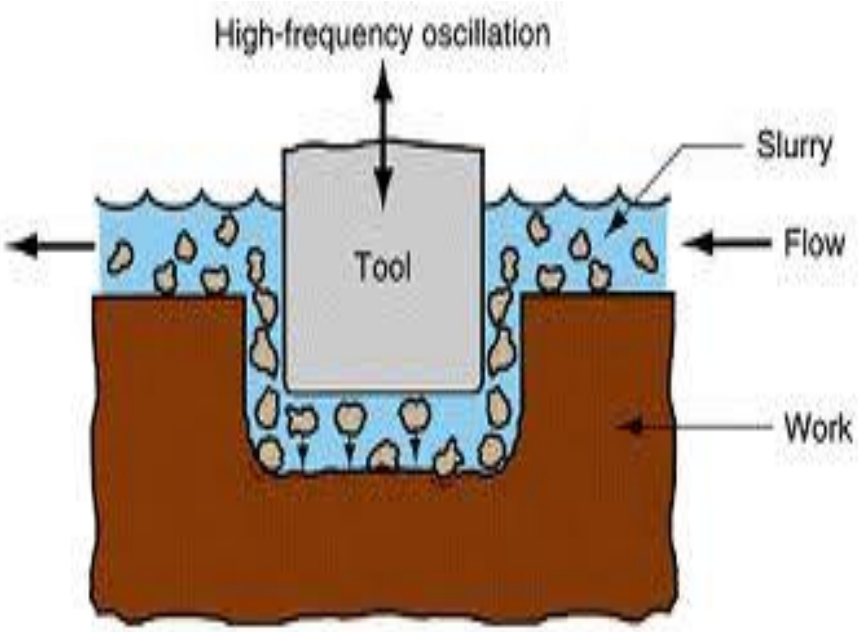
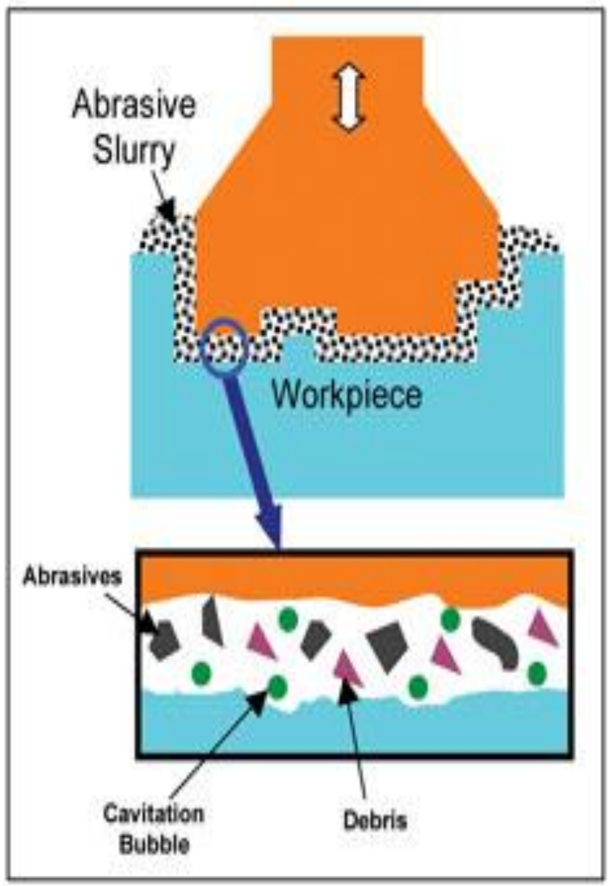


Fig: Principles of USM

The shape machined depends on the shape of the tool used.







ULTRASONIC MACHINING (USM)

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

WORKING PRINCIPLES (cotd)

The workpiece surface is bombarded by the abrasive particles at high velocity and the machining process involves:

- High intensity stressing leading to disintigration of surface
- Abrasive cutting of surface
- Breakdown of abrasive particles by crushing.

Mechanisms of material removal:

- Hammering of abrasive particles on work surface by tool
- Impact of free abrasive particles on work surface
- Erosion due to cavitation (<5%; prevalent when machining graphite)
- Chemical action associated with fluid used.

Ultrasonic machining (also known as **ultrasonic impact grinding**), combines ultrasonically-induced vibrations with abrasive slurry to create accurate cavities of virtually any shape in hard, brittle materials. By using this stress free machining, non-thermal, non-chemical and non-electrical process, the metallurgical, chemical or physical properties of the material being used to create a component are not changed.

USM capabilities:

- In excess of 10,000 holes drilled simultaneously
- Types and shapes
    - Round, square or custom shapes in most hard, brittle materials
    - Aggresive aspect ratios
    - Capable of holes as small as 0.45 mm.
- Materials: Silicon, silicon carbide, silicon nitride, glass, quartz, alumina, sapphire, graphite
- Custom designs

EQUIPMENT DESCRIPTION

The component parts of the equipment required are:

- Vibration **power generator**
- **Vibration head** (or acoustic head)
- **Abrasive unit**

The power generator comprises a power oscillator (15 to 40 kHz) from 25 W to 25 kW, and an output transformer for feeding into the vibrating head.

The vibrating head comprises two parts:

- Electromechanical **transducer**
- Velocity transducer or **concentrator**

The vibrating head converts the high frequency output of the power generator into linear vibrations, the displacements of which are then amplified by the concentrator.

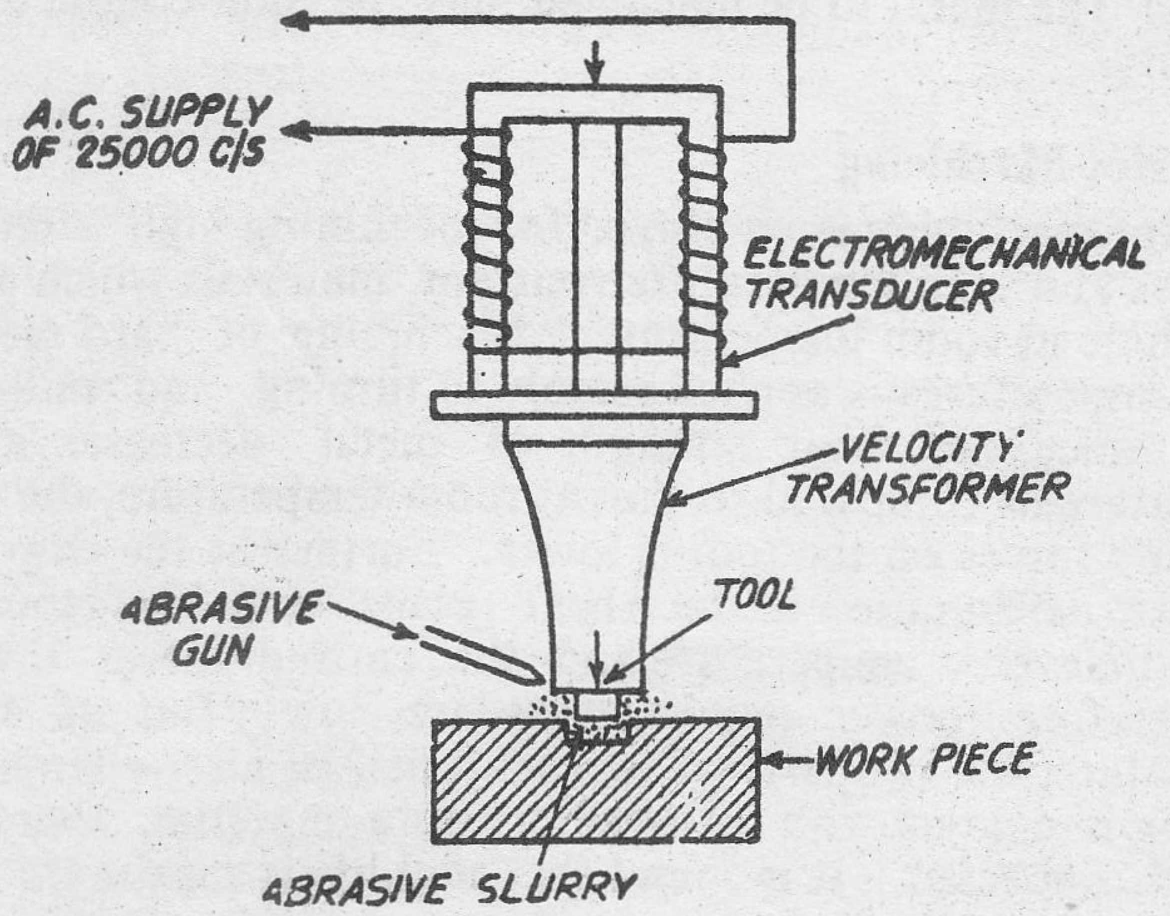
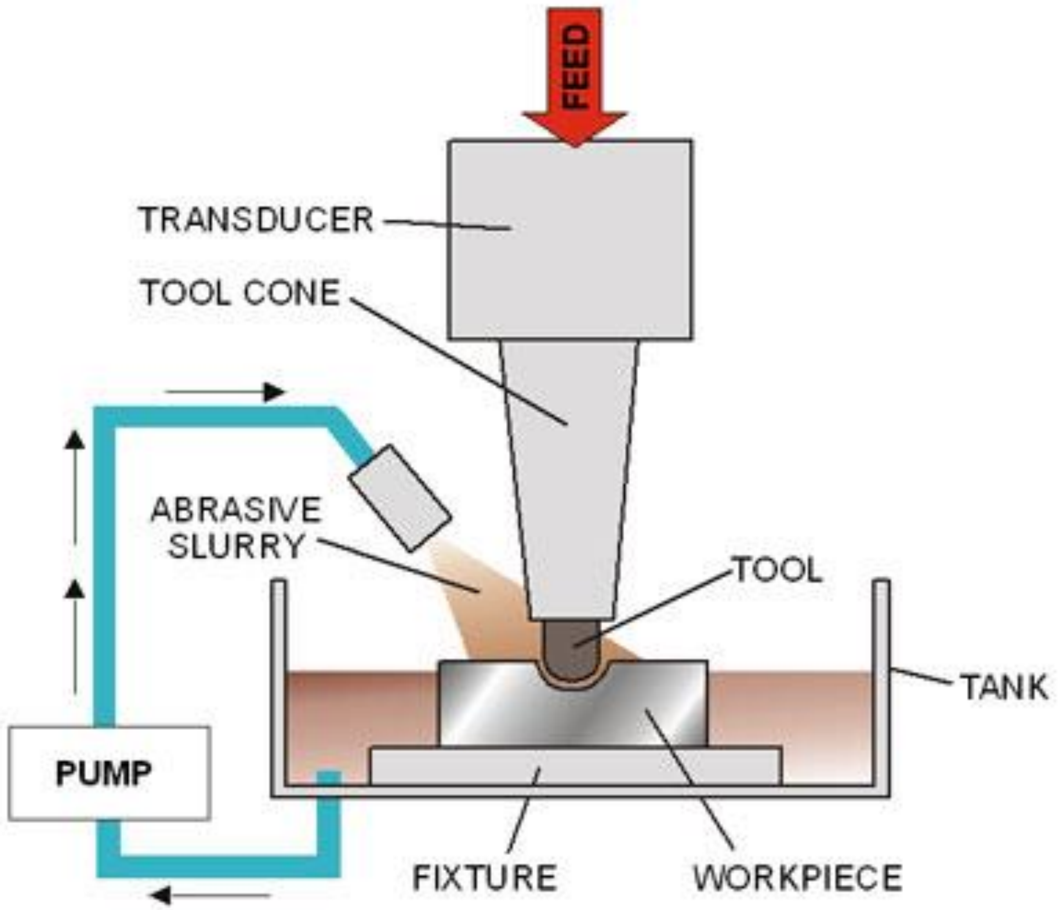

A.C. SUPPLY
OF 25000 C/S
ELECTROMECHANICAL
TRANSDUCER
VELOCITY
TRANSFORMER
ABRASIVE
GUN
TOOL
WORK PIECE
ABRASIVE SLURRY

Fig. 10·14.


FEED
TRANSDUCER
TOOL CONE
ABRASIVE
SLURRY
TOOL
TANK
PUMP
FIXTURE
WORKPIECE

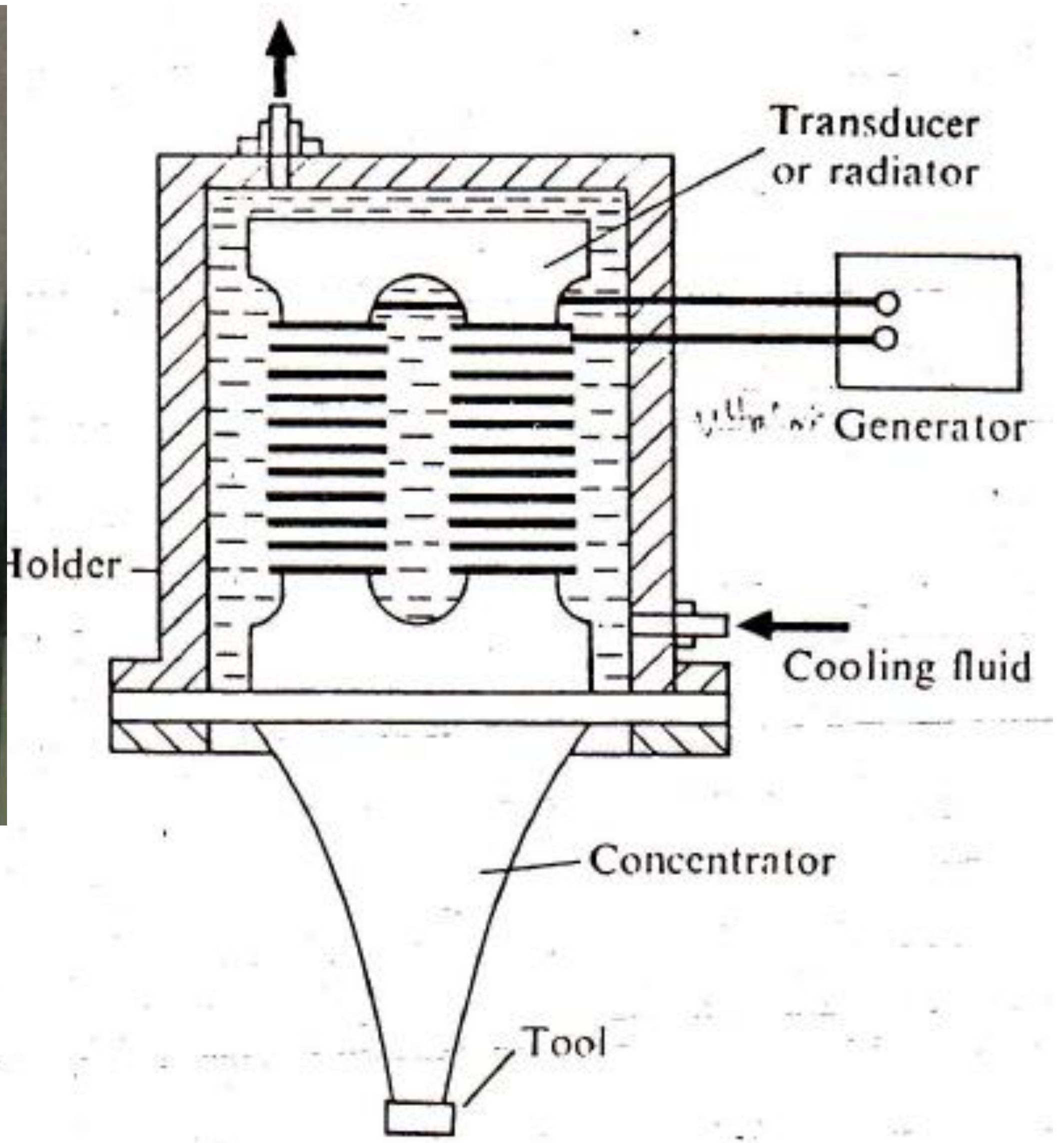


Fig. 6.22 Simplified diagram of acoustic head.

Electromechanical Transducer

In USM, the tool is vibrated at high frequency of 20 – 40 kHz.
Vibration is produced by electromechanical transducer.

Two types of electromechanical transducers:

1) Magnetostrictive transducer
2) Piezoelectric transducer

Magnetostrictive transducers utilize the magnetostrictive property of a material to **convert the energy in a magnetic field into mechanical energy**. The magnetic field is provided by a coil of wire which is wrapped around the magnetostrictive material.

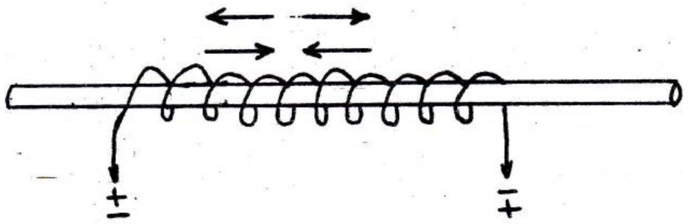
Piezoelectric transducers utilize the piezoelectric property of a material to **convert electrical energy directly into mechanical energy**.

Both types of transducers have advantages and disadvantages.

MAGNETO STRICTOR

When a magneto strictor is used, the vibration is obtained from magneto-striction effect.

Magneto-striction: a material exhibits a change in length when subjected to a magnetic field. Reversal of field will reverse change in length. An alternating field will produce vibrations in the longitudinal axis. Amplitude of vibrations will be maximum when frequency of alternating field corresponds with natural vibration frequency of the rod.

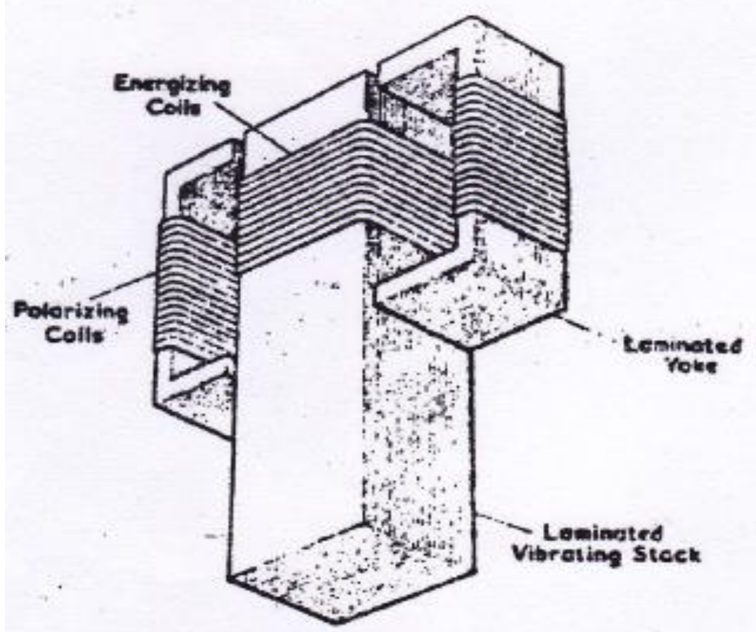


Nickel-iron and aluminium-iron alloys exhibit maximum magnetostrictive property.
Magnetostrictive transducer is used for this purpose.

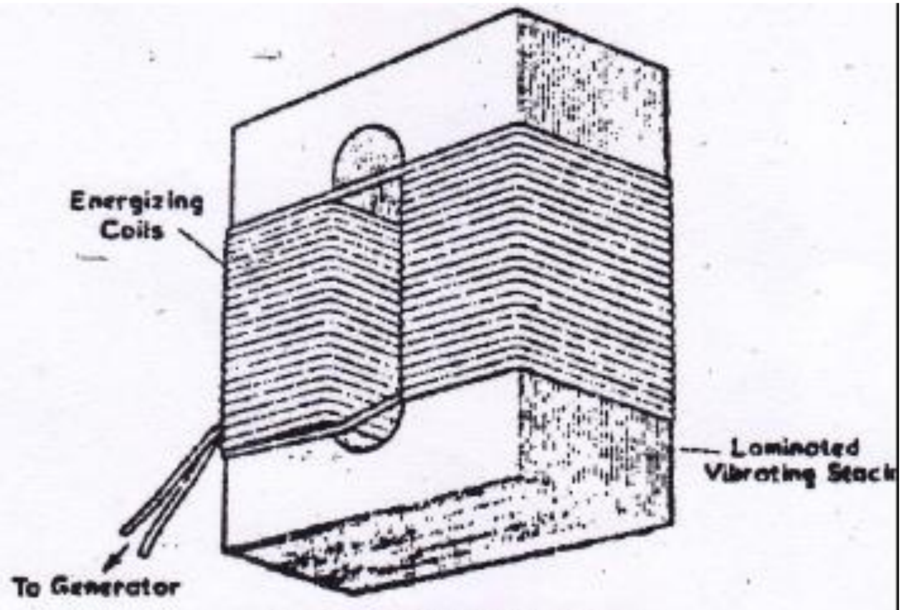
The transducer consists of a laminar stack around which coils are wound.
The transducer is magnetised by DC in the polarised coil.

Two designs of magneto-strictive transducer:

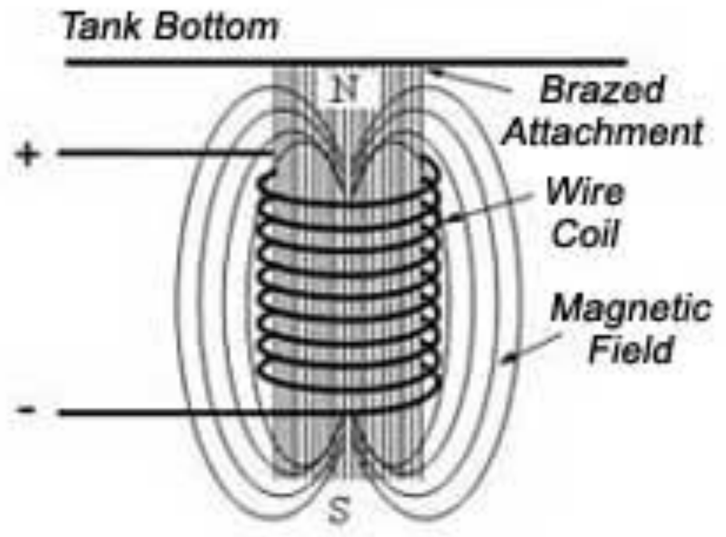
- ✓ Window type – suitable for small machines up to 250 W
- ✓ Double-bell type – used with a water-cooled jacket for larger powers.



(a) Window Type



(b) Dumb-bell Type - used with a water-cooled jacket



Example of magnetostrictive transducers used in power ultrasonic cleaning application.

Magnetostrictive transducers consist of a large number of nickel (or other magnetostrictive material) plates or laminations arranged in parallel with one edge of each laminate attached to the bottom of a process tank or other surface to be vibrated. A coil of wire is placed around the magnetostrictive material. When a flow of electrical current is supplied through the coil of wire, a magnetic field is created (just like high power lines). This magnetic field causes the magnetostrictive material to contract or elongate, thereby introducing a sound wave into the cleaning fluid.

Capacity of magneto strictor is measured by **coefficient of magnetostrictive elongation**, ε_m

$$\varepsilon_m = \frac{\Delta\ell}{\ell}$$

where: $\Delta\ell$ = elongation

ℓ = original length of magnetostrictive core.

If mode of vibration wavelength is in the middle, maximum amplitude is at $\lambda/4$ from the mid-point. So, maximum elongation is produced when $\ell = \lambda/2$.

Wavelength is calculated from:

$$\lambda = \frac{c}{f} = \frac{1}{f\sqrt{(\frac{E}{\rho})}}$$

where: c = speed of sound (m/s) in magneto strictor material

f = frequency (1/s)

E = Young's modulus (Mpa)

ρ = density (kg/m^3)

Table 8.1 Properties of magnetostrictive materials (Data from Kaczmarek, 1976)

Material	*Coefficient of magnetostrictive elongation* ($\times 10^6$) ϵ_{ms}	*Coefficient of magnetomechanical coupling* k_r
Alfer (13% Al, 87% Fe)	40	0.28
Hypernik (50% Ni, 50% Fe)	25	0.20
Permalloy (40% Ni, 60% Fe)	25	0.17
Permendur (49% Co, 2% V, 49% Fe)	9	0.20

Table 8.2 Influence of brittleness criterion on efficiency of USM

Brittleness criterion τ_x	*Efficiency of USM*	*Typical materials*
$\tau_x > 2$	High	Glass, quartz, ceramic, diamond
$1 < \tau_x < 2$	Medium	Tempered steels, hard alloys
$0 < \tau_x < 1$	Low	Copper, lead, most steels

To fulfill the above, **resonance frequency** must be satisfied:

$$f_r = \frac{1}{2\ell\sqrt{(\frac{E}{\rho})}}$$

Amplitude of vibrations produced by a typical magneto strictor ≈ 0.001 to 0.1 μm.

Amplitude suitable for effective machining ≈ 10 μm (0.01 mm).

To obtain this amplitude, mechanical transformer is fixed between transducer and tool.

This is known as **velocity transformer** or **concentrator**.

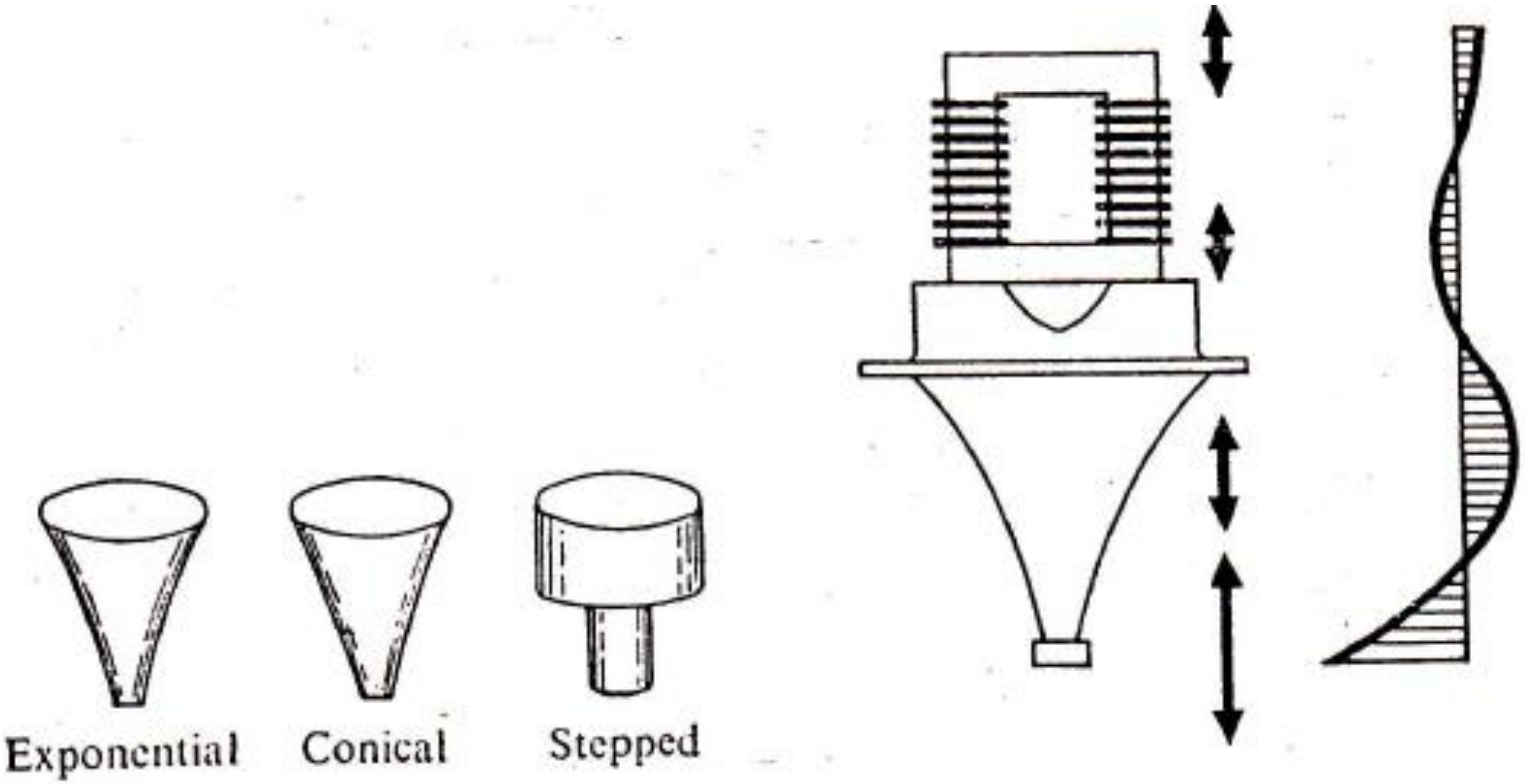
Several designs of velocity transformer/concentrator are available:

- ✓ **stepped**
- ✓ **conical**, and
- ✓ **exponential**.

The amount of **linear amplification** is a function of:

- ✓ Shape
- ✓ cross-sectional **area at the two ends** of the transformers
- ✓ length

Maximum amplitude of vibration is obtained by making length of concentrator = multiple of **half wavelength** of sound through the magneto-strictor material. Thus, **resonance** is produced and **maximum amplitude** is transferred to the tool.



(a) Types of concentrators

(b) Mode of longitudinal vibration of the transducer-concentrator assembly, indicating how vibration is amplified

Fig. 6.23 Concentrators and their function.

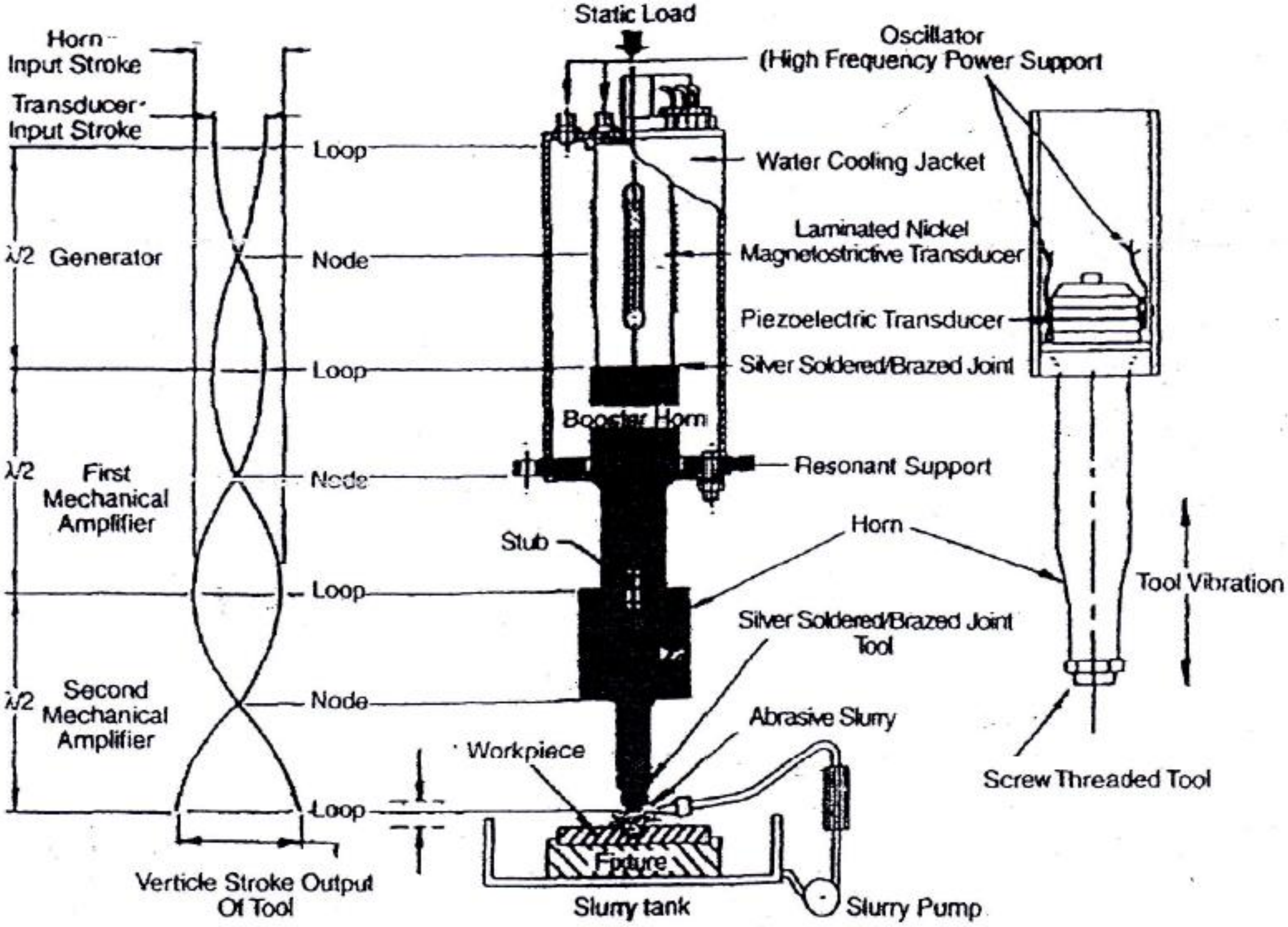


Fig. 1. Basic elements of USM head [28, 36–40].

Efficiency of USM operation depends on:

1) Selection of magneto-strictor material with high saturated magneto-strictive coefficient,

$$\varepsilon_{ms} = \frac{\Delta \ell_s}{\ell} \qquad \varepsilon_{ms}$$

where $\Delta \ell_s$ = saturated elongation of magneto-strictor

2) High coefficient of magneto – mechanical coupling, k_r

$$k_r = \sqrt{(E_w / E_m)}$$

where: E_w = magnitude of mechanical energy

E_m = magnitude of magnetive energy

This is because magnetive energy needs to be transformed to mechanical energy.

3) High fatigue strength of concentrator.

MAGNETO STRICTOR (cotd)

Limitation of magneto-strictive transducer is low efficiency, as low as 55 %.

The transducer heats up and needs to be cooled.

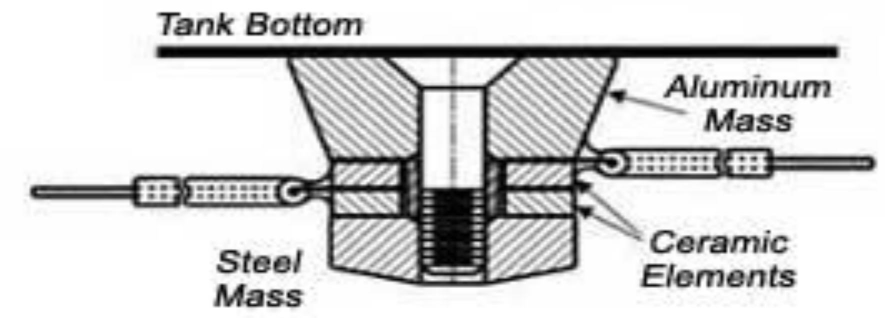
The other type of electromechanical transducer is piezoelectric transducer with efficiency ≈ 90 – 95 %.

Piezoelectric transducers are extremely efficient due to the direct conversion of electrical to mechanical energy in a single step. Direct application of the power to the piezo-electrically active ceramic causes it to change shape and create the sound wave. Energy losses in the ceramic due to internal friction and heat are typically less than 5%.

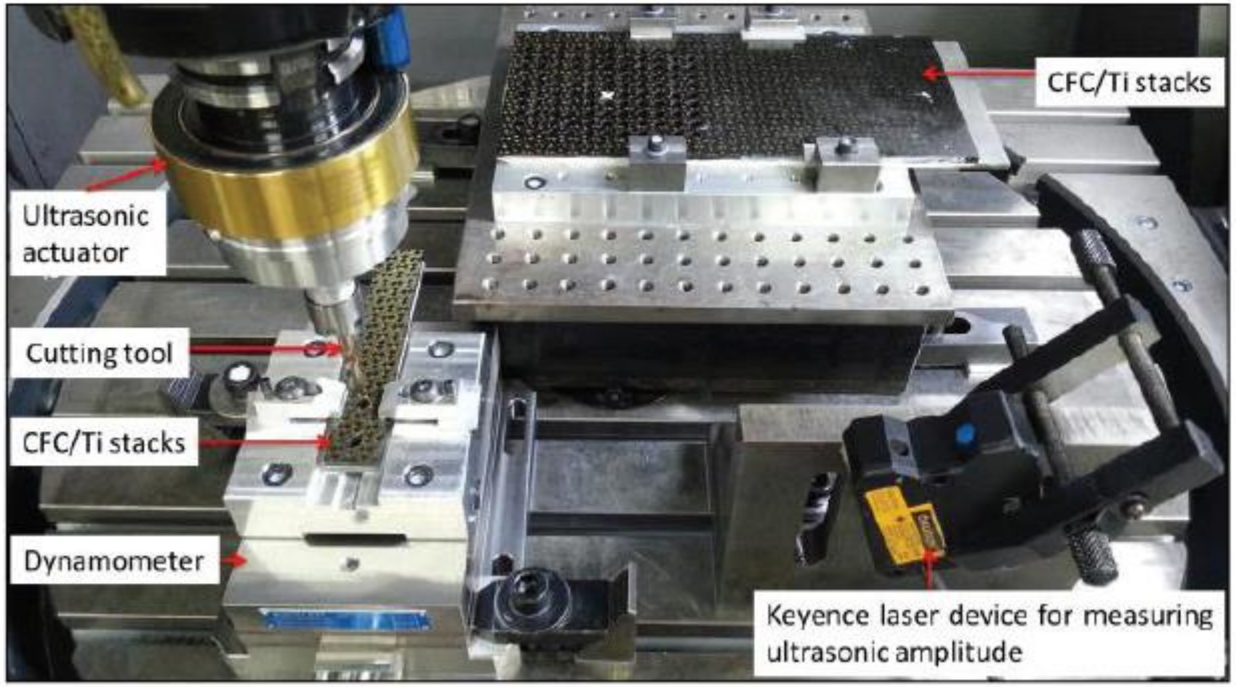
PIEZOELECTRIC TRANSDUCER

Piezoelectric transducer works on the principle that a body will change its dimension when subjected to electrical field. Synthetic ceramics, such as lead titanate-zirconate (PZT) is good for this purpose.

A piezoelectric transducer consists of a single or double thick disc of piezoelectric ceramic material (typically PZT), sandwiched between electrodes which provide the attachment points for electrical contact. The ceramic assembly is compressed between metal blocks (one aluminum and one steel) to a known compression. When a voltage is applied across the ceramic through the electrodes, the ceramic expands or contracts (depending on polarity) due to changes in its lattice structure.



ULTRASONIC ASISSTED MACHINING



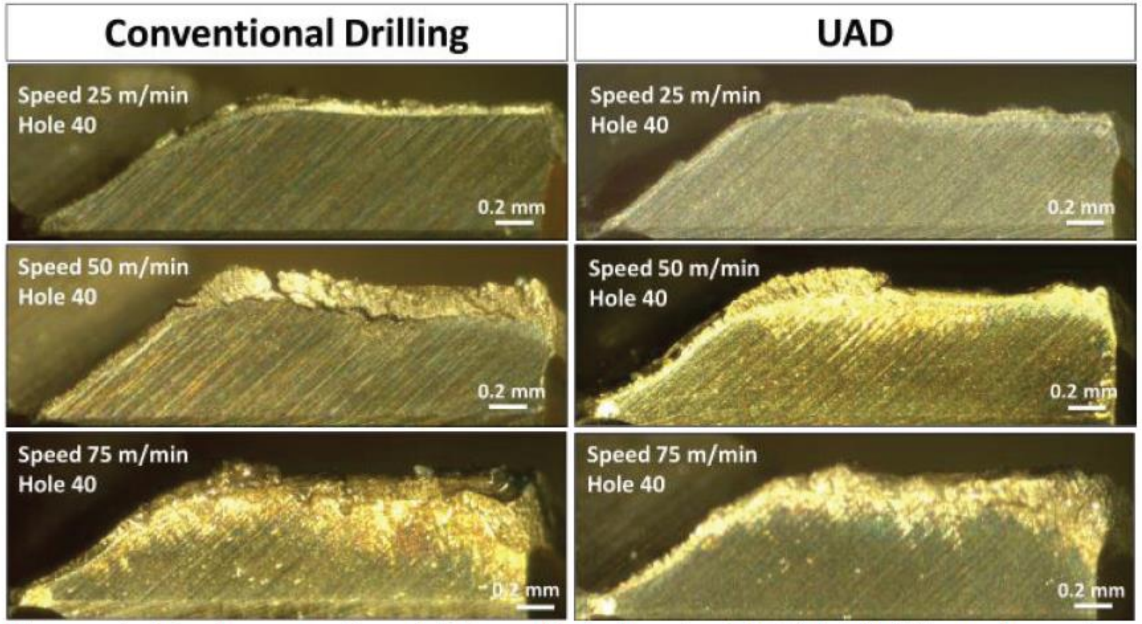


Figure 5: Tool wear after drilling 40 holes in CFC/Ti6Al4V stacks using cutting speed of 25, 50 and 75 m/min conventionally and with ultrasonic.

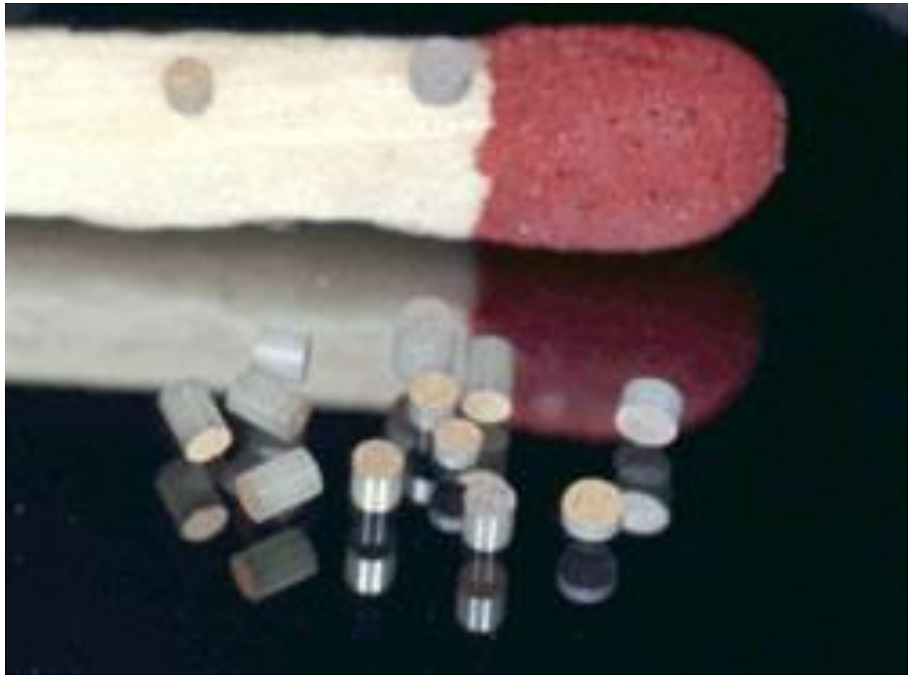
Examples of products using USM

Form drillings in HPSN, hot pressed silicon nitride.

Machining purpose: stress-free machining of highly stressed parts without changing the material characteristics. The main application lies in the machining of difficult to machine ceramic materials and in the requirement to treat this material without production of microcracks and stresses.

Machining time: approx. 12-15 min at abt. 16mm dia. and a length of approx. 6 mm perform drilling.

Examples of products using USM



Piezo-resonators.
Material: piezoceramics PPK 22/21.
Machining purpose: production of sensors.
The resonators are cut out most efficiently from ceramic substrate by means of a hollow drilling tool.
Machining time: approx. 3-5 seconds per unit.

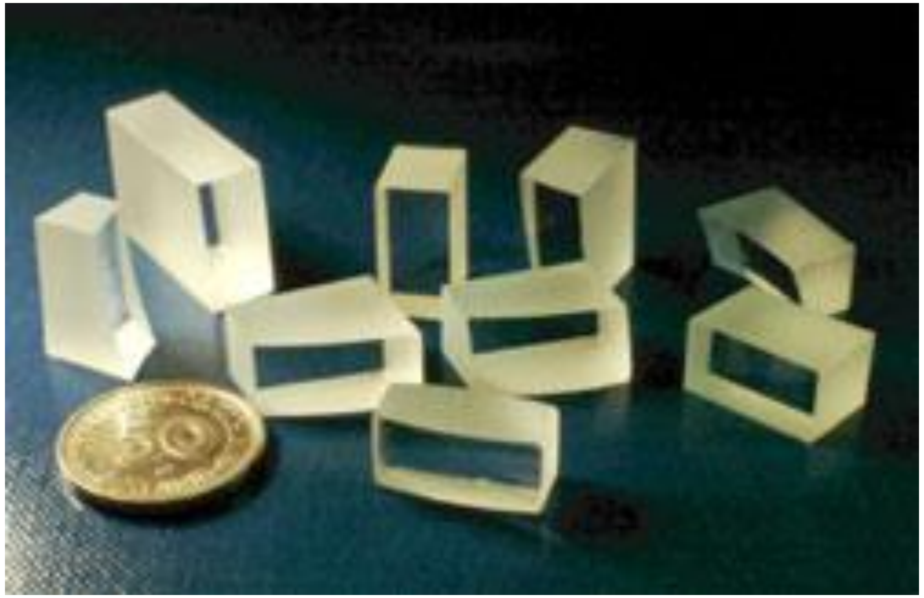
Examples of products using USM

Material: silica glass.

Machining purpose: machining tests with three-dimensional shaped tools to determine machining values and tool wear. Such tests are performed with the original material in order to check exact dimensioning of the tool and adapt it to the drilling procedure, taking into account the different machining parameters (cutting agent grits, tool wear and its compensation, oscillating quality of the sonotrode with tool).

Processing time: with a material thickness of 10 mm, the rectangular profile drilling requires a machining time of apt. 3 minutes, without suction device for the grinding agent. In this case a special feed device is used.

Examples of products using USM



Glasses. Material: optical glasses (lenses).

Machining purpose: production of optical systems to minimize the dimensions of the total optic. The required area of the path of the rays can be extracted from an optical module and combined with other components.

Processing time: varying; speed rate approx. 1 mm/min.

Examples of products using USM

Material Silicon carbide SiC.

Machining purpose: shaping of the parts from plates for fine machining. Check on tendency to form cracks SIC is a very hard material; however, cracks were not observed.

Processing time: approx. 0.3 mm/min.

Examples of products using USM

Profiled piece. Material: HPSN (hot isostatic pressed silicon nitride).

Machining purpose: production of thermically high stressed set collars, The material is difficult to work. However, very good quality results can be achieved.

Processing time: the speed rate amounts to approx. 0.5 mm/min.

Examples of products using USM

Material: monocrystalline silicone.

Machining purpose: machining tests, production of drilling cores, tests with multiple profiled tools. The Test serves to determine the machinability of the material compared to polycrystalline silicone. The utilisation of hollow drilling tools of 20mm dia, rate of feed approx. 2 mm/min, resulted in insignificant, but permissable edge tearings.

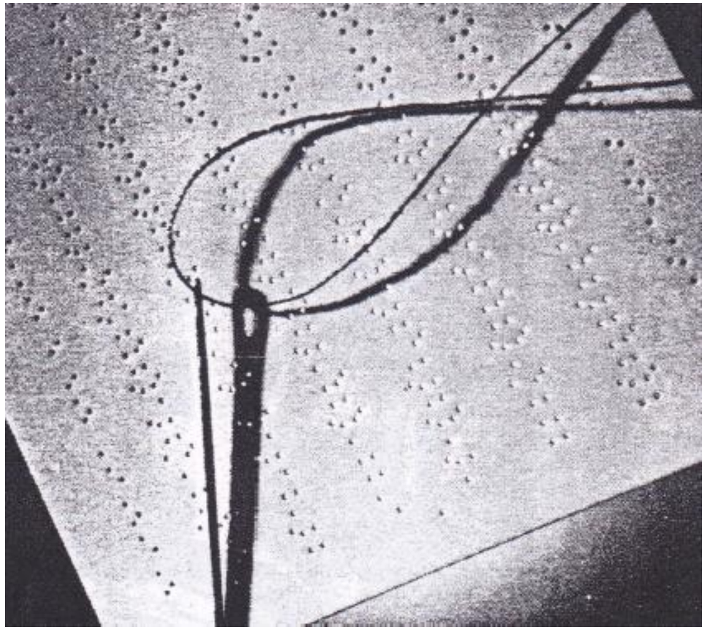
Examples of products using USM

Magnetic cylinders.

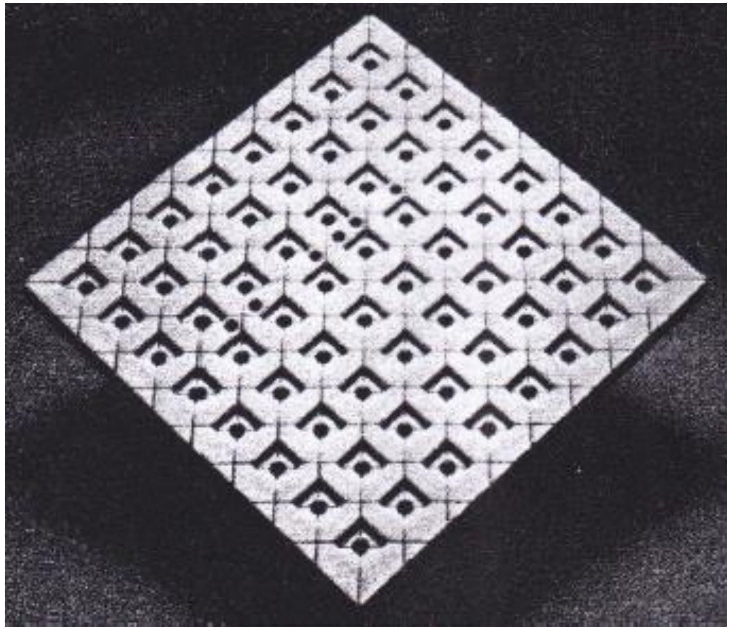
Material: Nd Fe B magnetic material.

Machining purpose: production of small magnetic rods from square raw substrates. Due to its structure, the material is relatively difficult to machine. However, working very carefully, good results without formation of cracks can be achieved.

Processing time: approx. 1.3 mm/min.

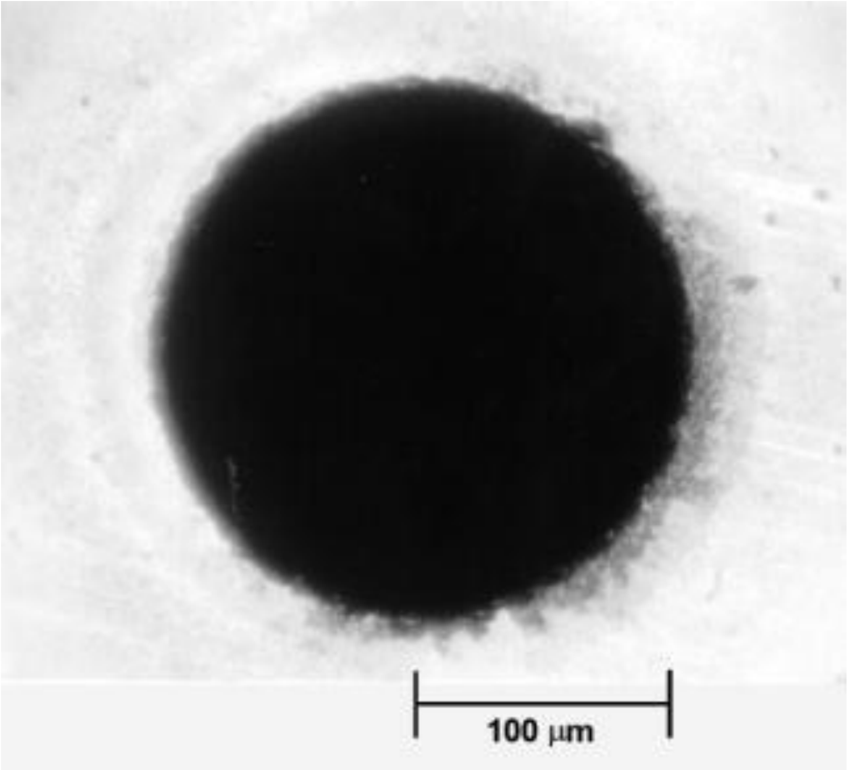


Microholes



Square cavities and through holes in alumina. Locational accuracy of square cavities: 0.05 mm of true position

Examples of products using USM



Micro Ultrasonic Machining (MUSM)
Material: Ceramic
Hole diameter = 200 μm

USM

DMS Ultrasonic 35 features a 350 mm X travel and rapid traverse and feed rate of 5 m/min

TOOL MATERIAL

General considerations

For an effective cutting operation, the following parameters need to be carefully considered:

- The machining tool must be selected to be highly wear resistant, such as high-carbon steels.

- The abrasives (25-60 μm in dia.) in the (water-based, up to 40% solid volume) slurry includes: Boron carbide, silicon carbide and aluminum oxide.

Tool (cotd)

Tool **material** should have the following properties:

- ✓ High **wear** resistance
- ✓ High **fatigue** strength

- **Soft** tool materials, such as aluminium or copper, are subject to plastic deformation during cutting.
- Very **hard** materials, such as carbide and hardened tool steels, tend to fracture due to their brittleness when under high stresses.
- The **best** materials are tough malleable materials such as alloy and stainless steels.

Tool wear depends on tool and work materials. Examples: for glass, tools from tungsten carbide, copper or silver steel can be used; for cemented carbides, tools from silver or chromium-nickel steel can be used.

Tool (cotd)

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

If work material is hard, tool wear increases and may exceed stock removal.

The mass **length of the tool** is very important. Too great a mass absorbs much of the ultrasonic energy, reducing the efficiency of machining. **Long** tool causes overstressing of the tool. Most of the USM tools are less than 25 mm long. In practice the **slenderness ratio** of the tool should not exceed 20. The **under sizing** of the tool depends upon the grain size of the abrasive. It is sufficient if the tool size is equal to the hole size minus **twice the size of the abrasives**.

Selection of tool material depends on:

- Economic consideration
- Workpiece material.

Tool Material	*Work Material*	
	Glass	*Tungsten carbide*
Copper	1 : 200	—
Mild steel	1 : 100	1 : 1·14
Silver steel	1 : 220	1 : 3·85
Stainless steel	1 : 145	1 : 2·81
Brass*	1 : 50	1 : 0·70
Sintered tungsten carbide*	1 : 1000	1 : 0·90

***Note.**—*When brass or tungsten carbide tools are used to machine tungsten carbide, the tool wears more rapidly than the work material.*

TOOL WEAR

Tool wear has considerable effect on accuracy.

Two types of tool wear: longitudinal wear, lateral (or flank) wear.

Longitudinal wear

- Results from main cutting action, when tool impacts upon abrasive grains
- Depends mainly on physical condition of workpiece and tool materials.

Lateral wear

- Results from lateral cuting between tool flank and side of hole
- Influenced by undesireable transverse vibration of tool
- Causes tool to taper by up to 5°

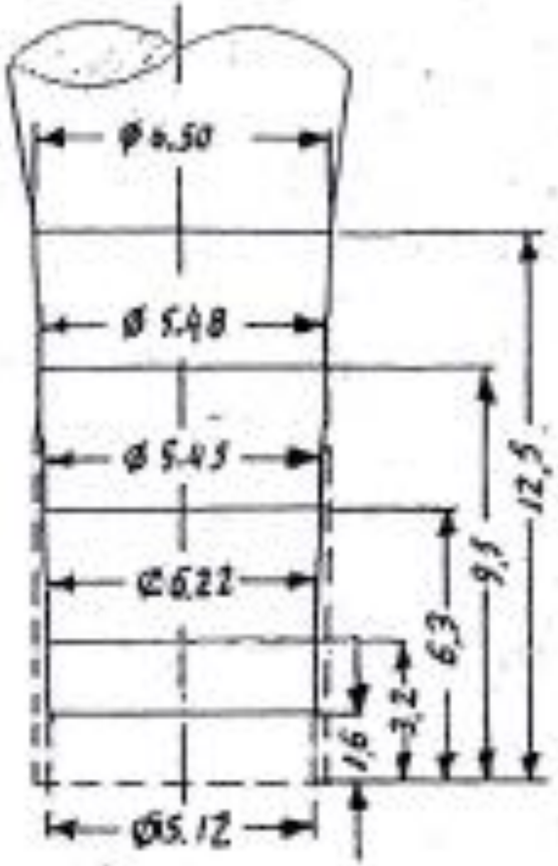


Fig 1: Change of profile caused by longitudinal and flank wear (Source: Markov, AI, 1966)

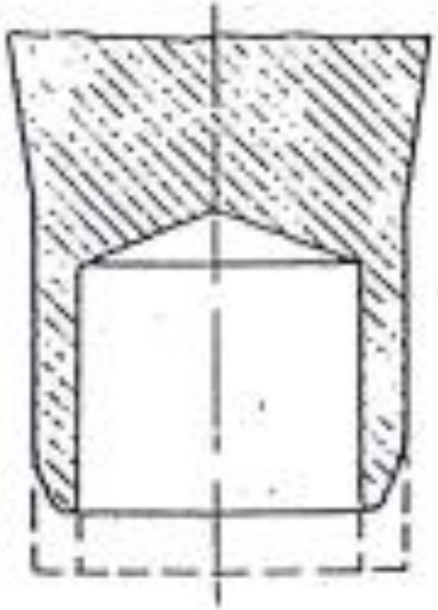
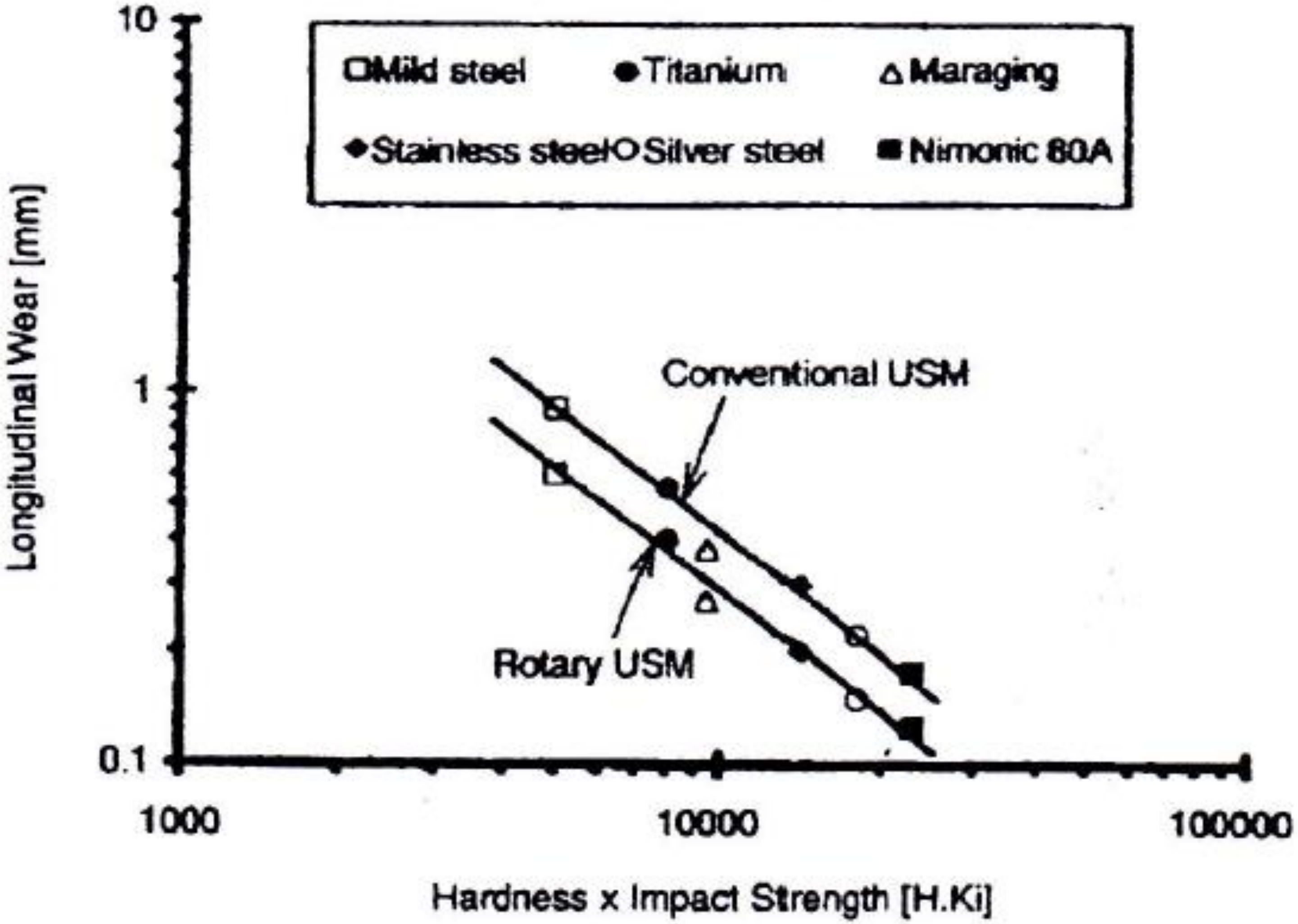


Fig 2: Taper caused by lateral wear (Source: Markov, AI, 1966)



Effect of the product of hardness and impact strength on longitudinal tool wear

ABRASIVES

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

Hardness of abrasive materials should exceed that of work material. It is one of the main parameters in determining machining and penetration rate.

Rate of penetration is also influenced (to a lesser extent) by the **size and shape** of abrasive particles. Rate of penetration increases with size of abrasives.

Abrasive **materials** normally used:

- Silicon carbide (Knoop hardness: 2050)
- Boron carbide (Knoop hardness: 2250)
- Aluminium oxide (Knoop hardness: 1650)

Boron carbide is used to machine tungsten carbide, tool steels and gems.
Aluminium oxide can be used to machine glass and ceramics.

SLURRY

To provide constant supply of abrasive grains to cutting zone it is necessary to mix them in a liquid to form a slurry. The liquid serves the following **purposes**:

- enables efficient tranmission of vibration
- permits cavitation, causing turbulance in the cutting zone
- enables abrasive particles to flow in the cutting zone
- cools the tool and workpiece.

The liquid should possess the following **characteristics**:

- good wetting property
- low viscosity
- high density
- high thermal conductivity and specific heat.

Liquid used: water + detergent, industrial solvent.

Slurry (cotd)

The **concentration** of the slurry is 30 to 50 % by volume. It is determined mainly by its ability to flow easily between tool and workpiece.

When using large-area tools, the concentration is held low to avoid circulation difficulties.

The most important characteristic of the abrasive that highly influences the material **removal rate** and **surface finish** of the machining is the **grit size** or grain size of the abrasive.
It has been experimentally determined that a maximum rate of machining is achieved when the grain size becomes comparable to the tool amplitude. Grit sizes of 200-400 are used for **roughing** operations and a grit size of 800-1000 for **finishing**.

MATERIAL REMOVAL RATE

Relative material removal rates (f = 16.3 kHz, A = 12.5 µm, grain size = 100 mesh)

Work material	Relative removal rate
Glass	100.0
Brass	6.6
Tungsten	4.8
Titanium	4.0
Steel	3.9
Chrome steel	1.4

Typical **rate of penetration** (mm/min),
(using 16 kHz frequency, boron nitride abrasive 100 mesh):

Tool steel :	0.015,	Brass :	0.04,
Titanium :	0.025,	Ceramics :	0.40,
Tungsten carbide :	0.025,	Glass :	0.60.

MATERIAL REMOVAL RATE

Variables that influence rate of penetration:

- ✓ operating frequency
- ✓ amplitude of vibration
- ✓ static load
- ✓ tool material, tool shape, tool area
- ✓ depth of cut
- ✓ work material characteristics (#)
- ✓ abrasive properties
- ✓ abrasive size
- ✓ slurry composition
- ✓ slurry concentration.

(#) Work material **brittleness** and **hardness** are the main factors in influencing rate of penetration.

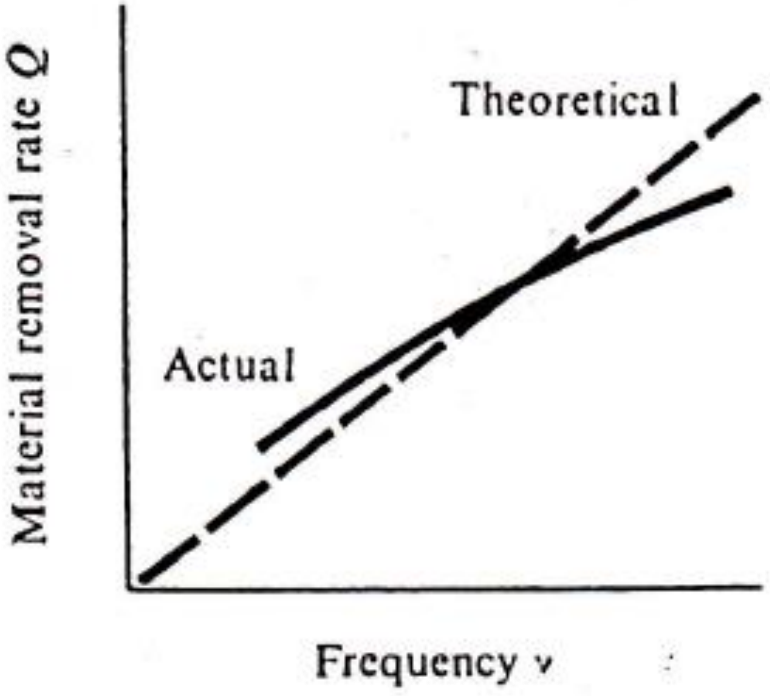
Penetration and Tool Wear Rates in Ultrasonic Machining (USM) at 700 Watts Input*

Material	Ratio Stock Removed To Tool Wear	Maximum Practical Machining Area		Average Penetrating Rate**	
		in.²	cm²	in./min	mm/min
Glass	100:1	4.0	25.8	0.150	3.81
Ceramic	75:1	3.0	19.4	0.060	1.52
Germanium	100:1	3.5	22.6	0.085	2.16
Tungsten carbide	1.5:1	1.2	7.7	0.010	0.25
Tool steel	1:1	0.875	5.6	0.005	0.13
Mother of pearl	100:1	4.0	25.8	0.150	3.81
Synthetic ruby	2:1	0.875	5.6	0.020	0.51
Carbon-graphite	100:1	3.0	19.4	0.080	2.00
Ferrite	100:1	3.5	22.6	0.125	3.18
Quartz	50:1	3.0	19.4	0.065	1.65
Boron carbide	2:1	0.875	5.6	0.008	0.20
Glass-bonded mica	100:1	3.5	22.6	0.125	3.18

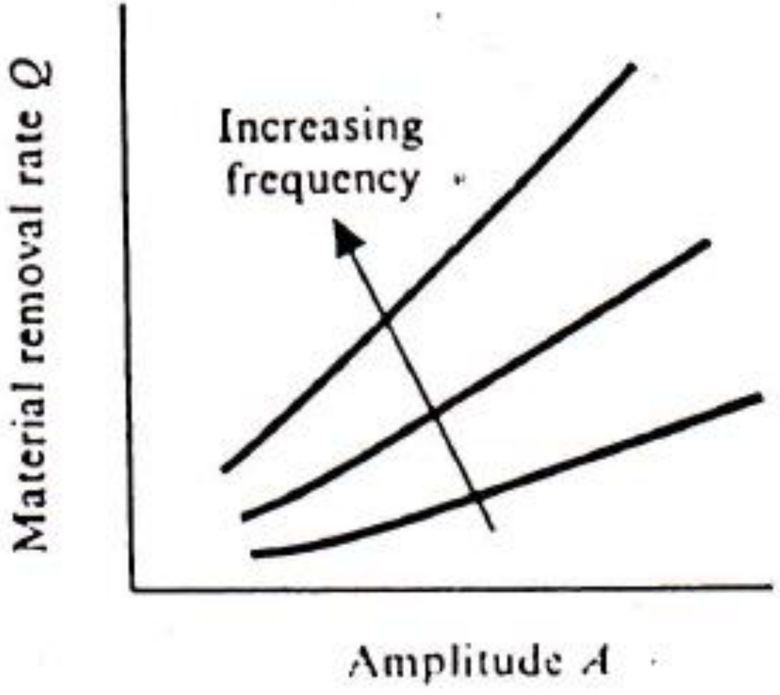
Source: Data from Raytheon Company, *Impact Grinders for Ultrasonic Machining*, 1961.

* Tool material; cold rolled steel in all cases; #320 mesh boron carbide abrasive.

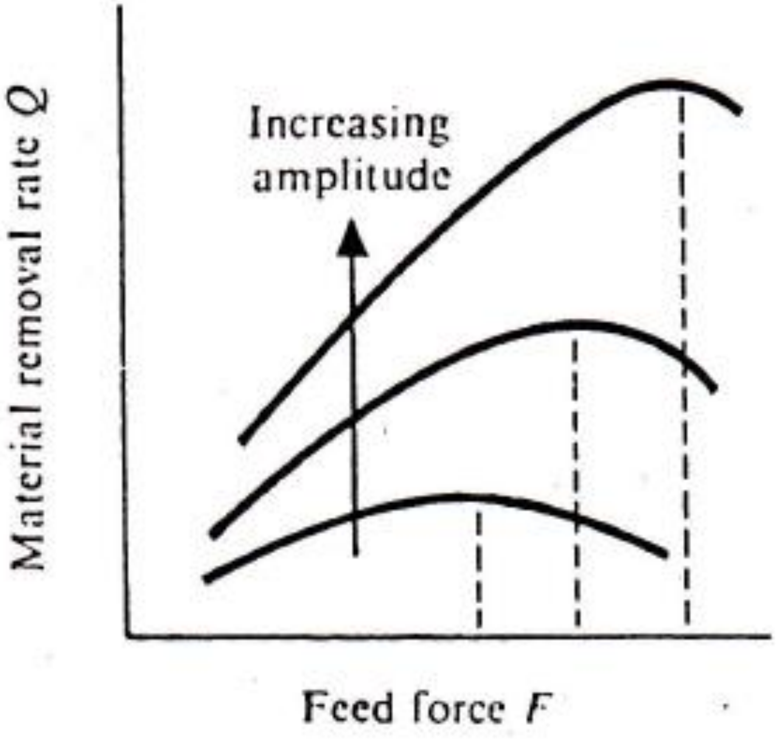
** ½" (12.7 mm) diam. tool; ½" (12.7 mm) deep.



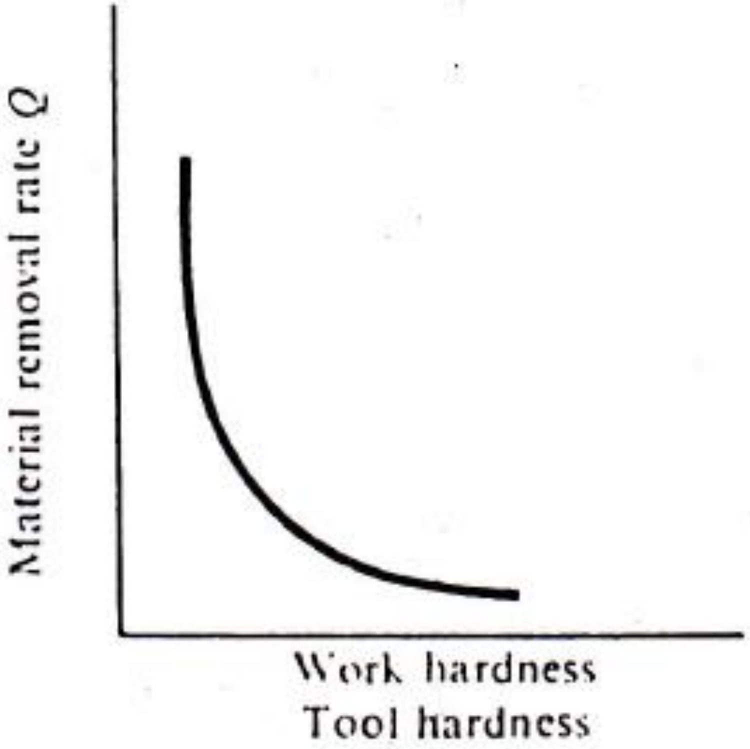
(a) Variation with frequency



(b) Variation with amplitude



(a) Variation with feed rate



(b) Variation with hardness ratio

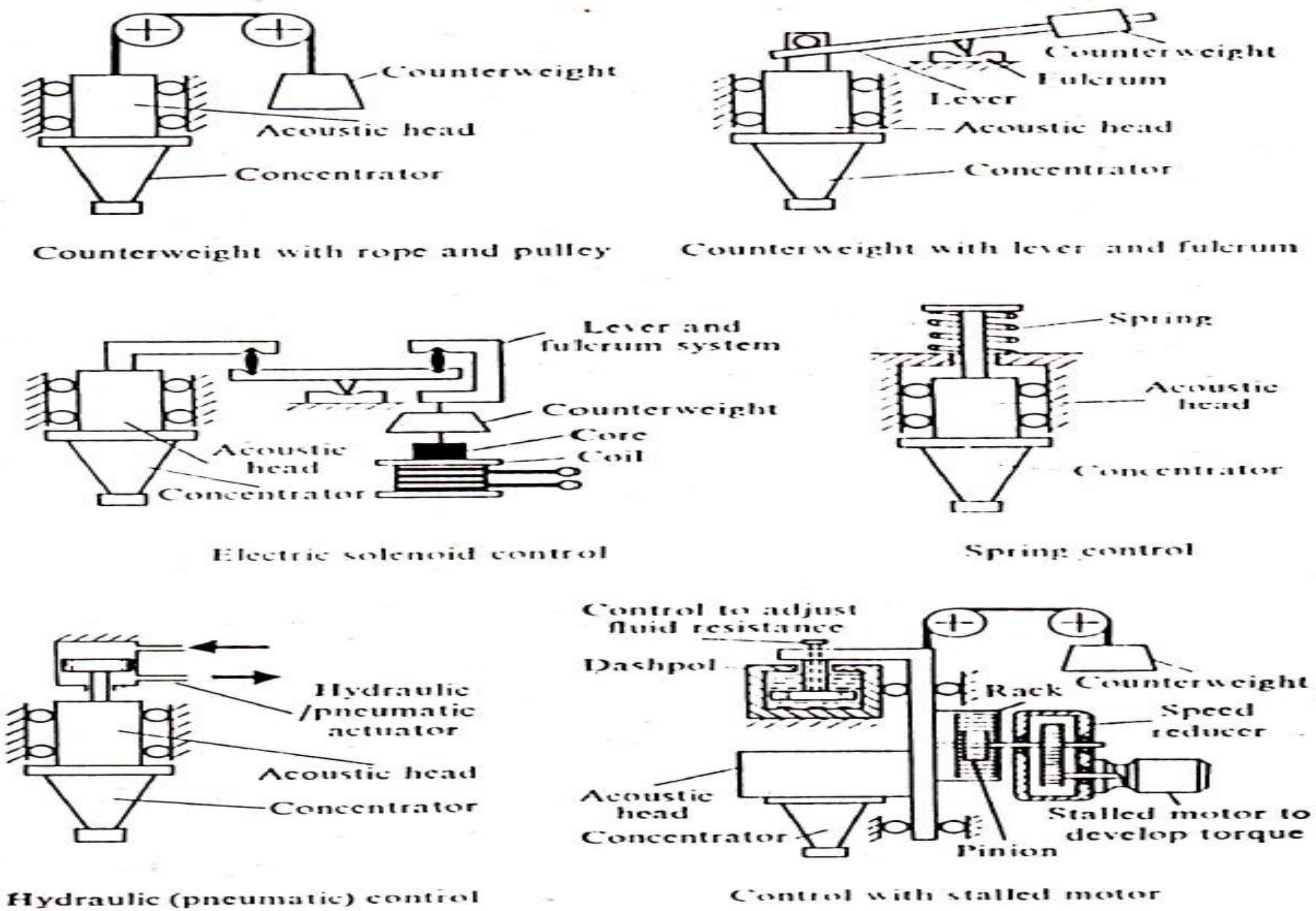


Fig. 6.24 Different feeding arrangements for USM units.

ACCURACY

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

Accuracy depends on:

- Abrasive grain size
- Tool wear
- Lateral vibration
- Depth of machining.

Depending on accuracy required, two or more passes may be required:

- roughing cut with an undersize tool and coarse abrasive results in a tolerance of about 0.1 mm for a 25 mm deep hole
- finishing cut with finer abrasive then results in a tolerance of 0.01 mm.

APPLICATIONS

Main application is to machine materials difficult to machine by other processes due to:

- ❑ High hardness value
- ❑ Non conducting material.

Other applications:

- ✓ Die-sinking
- ✓ Multiple hole drilling
- ✓ Production of curved holes
- ✓ Manufacture of wire drawing and extrusion dies.

Advantage of USM

USM process is a non-thermal, non-chemical, creates no changes in the microstructures, chemical or physical properties of the workpiece and offers virtually stress free machined surfaces.

- Any materials can be machined regardless of their electrical conductivity
- Especially suitable for machining of brittle materials
- Machined parts by USM possess better surface finish and higher structural integrity.
- USM does not produce thermal, electrical and chemical abnormal surface

Disadvantages of USM

- USM has higher power consumption and lower material-removal rates than traditional fabrication processes.
- Tool wears fast in USM.
- Machining area and depth is restraint in USM.

ROTARY ULTRASONIC MACHINING

(RUM)

PRINCIPLES OF ROTARY USM

The rotary USM process uses a power supply to generate high frequency electrical signal which is applied to a piezoelectric converter.

The converter changes the signal to a horn which in turn holds the rotating tool. The horn expands and contracts approximately 0.05 mm causing the tool to vibrate longitudinally.

The rotary system uses **diamond tools** which are plated or impregnated. The rotary motion (0 – 4,000 RPM) is variable and combined with the ultrasonic motion will machine most hard and/or brittle materials.

Benefits:

- combined action of rotary ultrasonic motion plus coolant (usually water) produces self-cleaning action that eliminates tool or core binding. This enables fast, efficient cutting at lighter tool pressure than with conventional machining

- lighter tool pressure is advantageous for drilling small holes (0.5 mm dia), deep holes (1 mm dia x 75 mm) or adjacent holes with thin dividing walls (0.125 mm)

- rotary ultrasonic action reduces friction between tool and workpiece which extends diamond tool life and reduces stress caused by common tool machining.

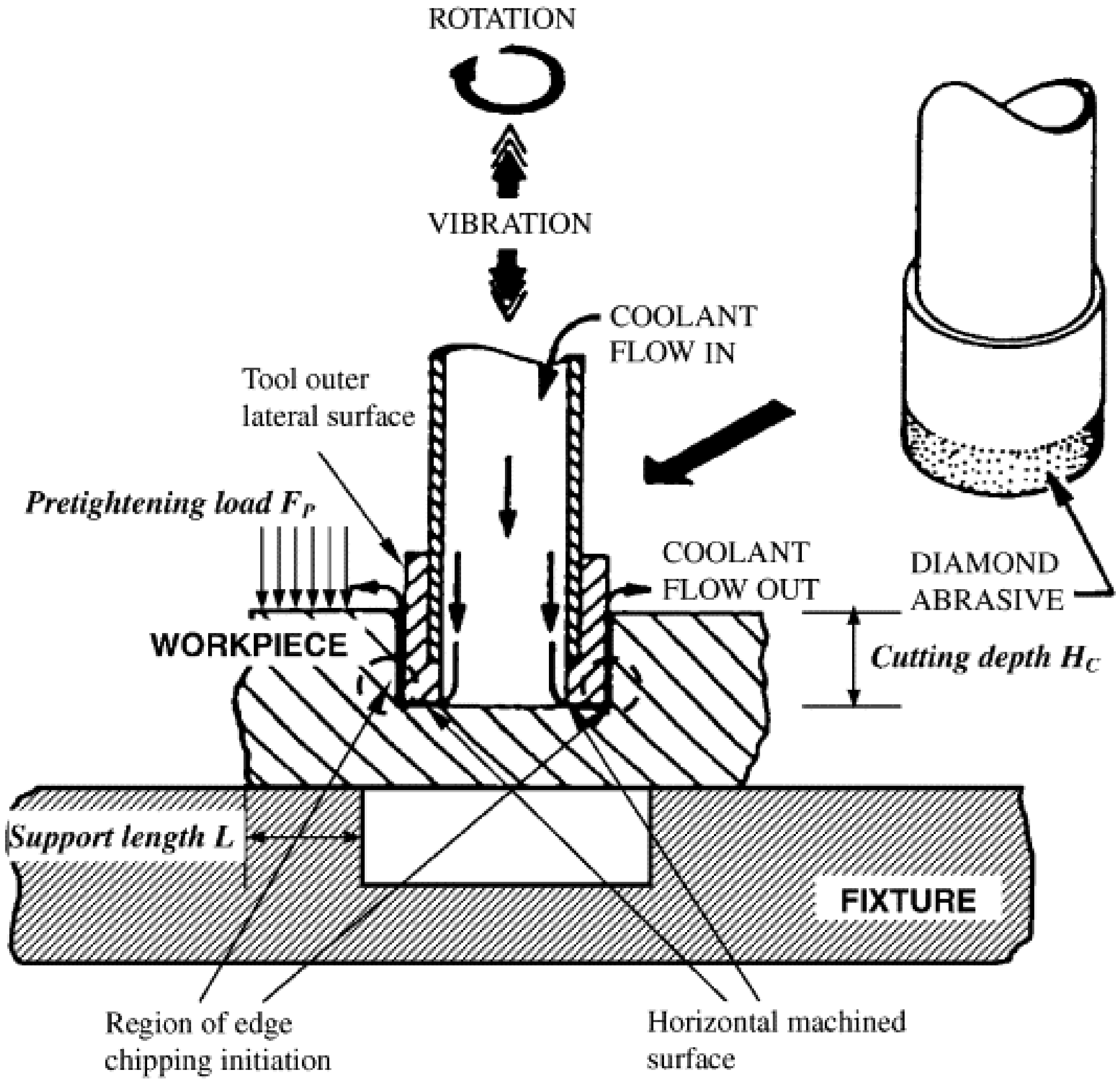


Figure: Rotary Ultrasonic Machine

Dr Sunil Pathak, PhD - IIT Indore (MP) India
Senior Lecturer
Faculty of Engineering Technology
University Malaysia Pahang, Kuantan Malaysia
https://www.researchgate.net/profile/Sunil_Pathak4
https://scholar.google.co.in/citations?user=9i_j3sMAAAAJ&hl=en