ELECTRONICS AND COMPUTER ENGINEERING

Lecture of Electroacoustics

Student Material, Issues and Problems for the Lecture of Ultrasonic Transducers

2. Specific Properties of Ultrasound

Freq. range division: infrasound, audible sound, ultrasound, hypersound.

Important features:

1) short-wave of ultrasound (nature of the rays),
2) high directivity and high intensity,
3) propagation in gases, fluids and solids (NOT IN VACUUM),
4) the presence of many phenomena, which we do not meet with the audible sound.

The definition of the ultrasonic wave length? Can you approximately specify ranges of values of ultrasonic longitudinal (L) wave speed in gases, fluids and solids?

3. Comparison of Sound and Ultrasound Intensity

Hearing threshold: 10^{-16} W/cm^2 = 0.1 fW/cm^2

Pain treshold: 10^{-4} W/cm^2 = 0.1 mW/cm^2

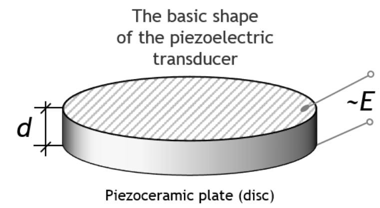
Conversation sound: $5.5\cdot10^{-11}$ W/cm^2 = 55 nW/cm^2

Large loudspeaker: $3.2\cdot10^{-5}$ W/cm^2 (10 m distance from) = 32 µW/cm^2

Artillery sound: 10^{-3} W/cm^2 (10 m distance from) = 1 mW/cm^2

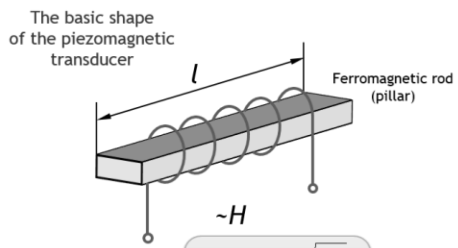
Ultrasound: up to 100 W/cm^2 (without any focusing)

4. Piezoelectric and Piezomagnetic Transducers



$$f_n = \frac{n}{2d}\sqrt{\frac{E}{\rho}}$$

c.a. 100 kHz - 15 MHz



$$f_n = \frac{n}{2l}\sqrt{\frac{E}{\rho}}$$

c.a. 15 kHz - 100 kHz

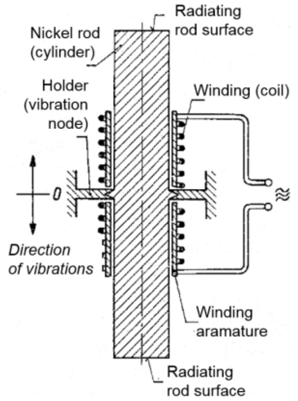
5. Various Constructions of Piezomagnetic Transducers

Rod transducer – type of vibrations?

Window transducer – type of vibrations?

Ring transducer type – type of vibrations?

6. Example of Piezomagnetic Transducer Probe



Why the transducer of that type is hold in the center of the vibrating rod?

7. Basic Piezoelectric Material (Quartz - Natural Piezoelectric Crystal)
Many combined vibrations → by different ways of cutting

Advantages?
Disadvantages?

8-9. Most Popular Piezoelectric Materials (Polycrystalline Ceramics – Fabrication Process)
Mixture of powders → milled for 40 h → formed and prepared by sintering in very high temperature (How much? How long?) → polarization process (2h) in temperature of 400 K with 20 kV/cm intensity of DC electrical field.

How the polarization process is going?
The properties of ceramic body before, during and after polarization?

10-11. Most Popular Piezoceramics

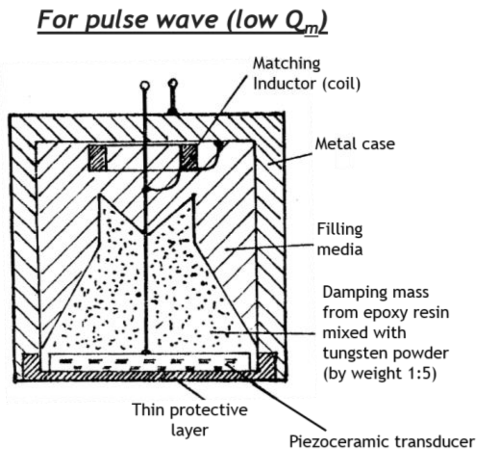
Lead Titanate-Zirconate
$PbZr_yTi_{1-y}O_3$
called PZT
High mechanical quality factor Q_m
Suitable for sending transducers
required more power (continous wave)
T_c = 370 °C

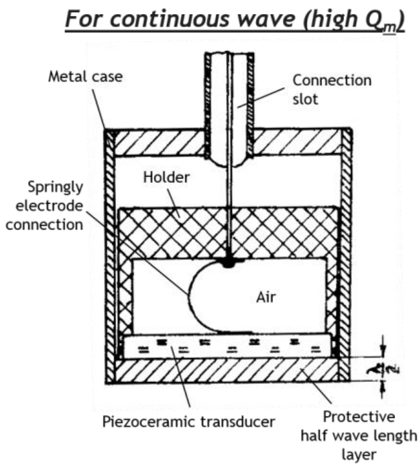
Lead Niobate $PbNb_2O_6$
Low mechanical quality factor Q_m
Particularly suitable for pulse operation
T_c = 570°C

Crystal Quartz: T_c = 573°C

Define the mechanical quality factor and the Curie point

12-13. Piezoelectric NDT Probe Construction

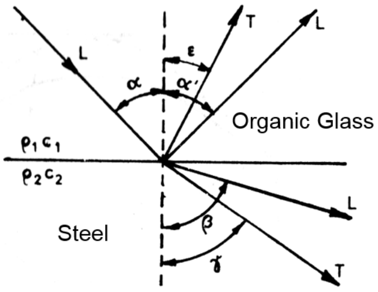




Where the positive and where the negative electrode is connected?

14. Ultrasound NDT Principles (Ultrasonic Inspection using Pulse Wave)
What is the principle of the ultrasonic non-destructive testing inspection basing on reflection effect?

Effect of wave dispersion – generating different ultrasonic wave modes:
longitudinal waves?
Tranversal (shear) waves?
Surface (Rayleigh) waves?



$$\frac{\sin\alpha}{c_{L_1}} = \frac{\sin\beta}{c_{L_2}} = \frac{\sin\gamma}{c_{T_2}} = \frac{\sin\varepsilon}{c_{T_1}}$$

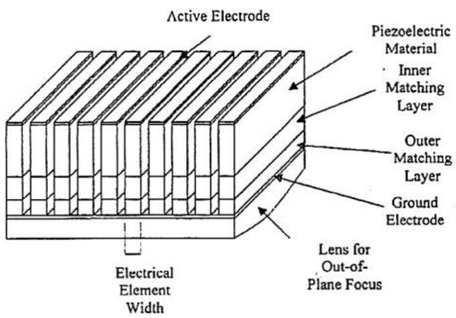
Generalized Snell’ equation: what we can calculate?

Effect of dispersion and reflection of ultrasonic waves on the border of solids
How it can be applicate in for ultrasonic inspection of defects in solids?
Whether the dispersion of ultrasonic waves occurs?

<u>15. Ultrasound Wave Propagation Modes</u>

Material	Longitudinal Waves		Transversal Waves	
	Speed, C_L [m/s]	Acoustic Impedance, Z_a [10^6 kg/m^{2}s]	Speed, C_T [m/s]	Acoustic Impedance, Z_a [10^6 kg/m^{2}s]
Air (20 °C)	330	0.00033	n.a.	n.a.
Water (20 °C)	1480	1.48	n.a.	n.a.
Standard Steel	5920	46.17	3240	25.27
Stainless Steel	5660	45.45	3120	25.05
Cast Iron	4800	35.04	2400	17.52
Aluminium	6320	17.12	3130	8.48
Copper	4660	41.6	2330	20.87
Titanium	6070	28.0	3310	14.91

<u>16. Multielement Ultrasonic Arrays (Medical Diagnostics Imaging)</u>



The way of dynamic beam forming - focusing (electronically)?

<u>17. Multielement Ultrasonic Arrays (Matching Layers)</u>

Front matching layer – what for?
Front matching layer thickness criterion?
How calculate the impedance of front matching layer?

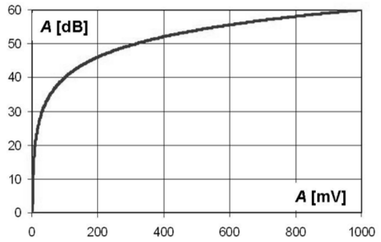
$$Z_2 = \sqrt{Z_1 \cdot Z_3}$$

Z_{PZT} = 30 MRayl
Z_{Pz37} = 17 MRayl (Ferroperm)
1 MRayl = 10^6 kg/(m^2·s)
Z_{Soft_Tissue} = 1.62 MRayl Z_{Water} = 1.48 MRayl Z_{Air} = 0.0004 MRayl

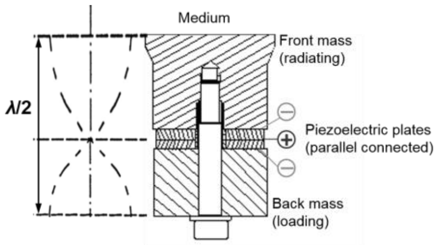
18. Ultrasonic Focusing Probe for Static Imaging (Mechanical or Manual Scanning)

The ways of mechanical focusing in ultrasonic transducers?
Which way is used in ultrasound B-mode scanner?

19. Multielement Ultrasonic Arrays (Medical Diagnostics Imaging)
In the conventional B-Mode imaging (USG), the ultrasonic echoes are converted on the glowing spots on the screen - brightness of spots is proportional to the amplitude of echoes -the brightness of the spot is modulated by the signal of echo, from black to white.



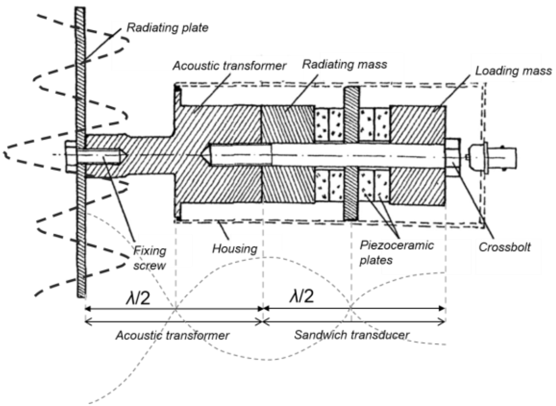
20. Sandwich Ultrasonic Transducers (High Power in Fluids)



It is designed to generate high power ultrasound in liquids and gases (as well as in tissues for cutting and ablation in surgery).
Range of working: f = 20 kHz – 50 kHz

21. Acoustic Transformers
They are attached to sandwich transducers by soldering (solder, brass, copper, silver) or threaded connectors.
Shape? Material?
Principle of working?

22. Sandwich Ultrasonic Transducer (High Power in Gases)



Industry application – the sandwich transducer with the radiating plate. The small longitudinal vibrations are transformed to large flexural transversal vibrations of the circular plate. We can achieve above 170 dB sound pressure level in air for low ultrasonic frequencies (about 20 kHz).

23. Sandwich Ultrasonic Transducer (High Power in Gases) – modification of the radiating plate

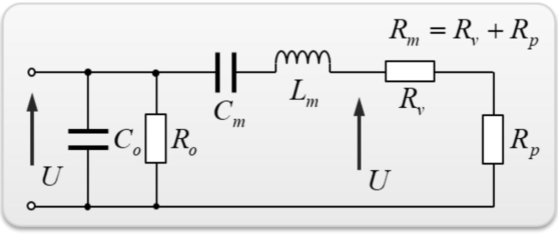
What is the way to increase the amplitude of the plate vibrations and generating plane ultrasonic wave with higher intensity?

24. Sandwich Ultrasonic Transducer with Radiating Plate (Exemplary Applications)

Applications?

25. Equivalent Circuit of Piezoelectric Transducer (near resonance)

Transducer can be presented as serial circuit (for piezoelectric transducers) with typical electrical and mechanical parameters.



Describe the elements.

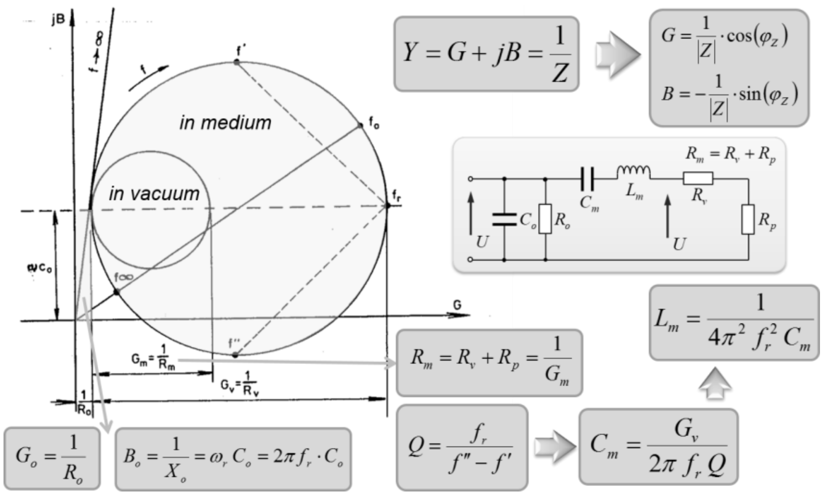
$$\eta_{ea} = \eta_{em} \cdot \eta_{ma} = \frac{R_o}{R_o + R_v + R_p} \cdot \frac{R_p}{R_v + R_p}$$

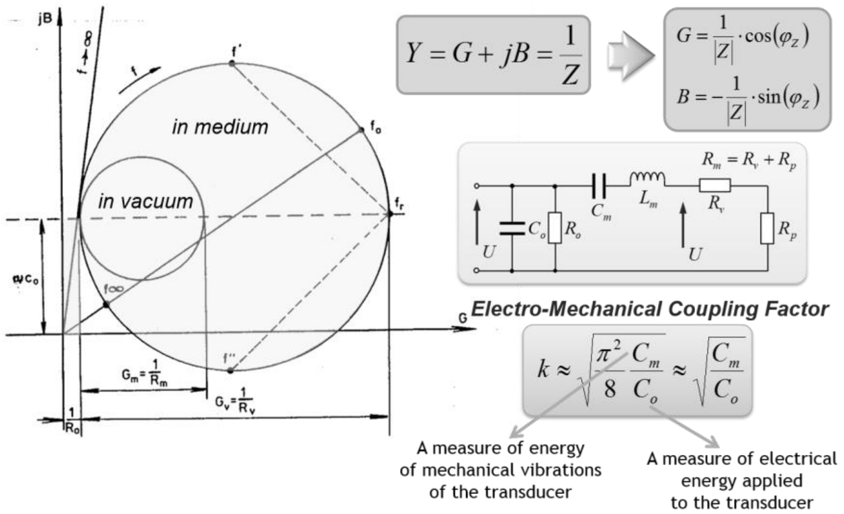
Parameters can be determined by Measurement: $|Z(f)|, \phi_Z(f)$

26-27. Admittance Characteristics for Ultrasonic Transducer (near resonance)

We can calculate from the measurements: $Y = G + jB = \frac{1}{Z}$ by $G = \frac{1}{|Z|} \cdot \cos(\phi_Z)$ and $B = -\frac{1}{|Z|} \cdot \sin(\phi_Z)$.

The parameters of the equivalent circuit can be determined from the complex admittance chart:





k – calculated from mechanical compliance (invers of the elasticity) and electrical capacity.
The ratio of mechanical to electrical energy – it is not efficiency but the measure of ability of energy transforming