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Transducers: Design and Applications

1. **Transducer**
   a. Definition: a device that converts one type of energy into another.
      i. Examples: stereo speaker, light bulb, most all "devices
   b. Ultrasound transducer vs. probe

2. **Piezoelectric effect**
   a. Definition and concept: the conversion of pressure energy into electrical energy
      i. PIEZO = pressure; PRESSURE = sound
      ii. ELECTRIC = electricity
      iii. Reverse piezoelectric effect = electricity into pressure (sound)
   b. History: first described by the Pierre and Jacques Curie in 1880.
   c. Piezoelectric materials:
      i. ISOTRPOIC vs. ANISOTROPIC
         1. Isotropic = symmetry of molecular structure and arrangement throughout material.
         2. Anisotropic = asymmetry of molecular structure which produces deformation of crystal when electrical force is applied. Conversely, deforming the crystal by applying pressure will produce an electrical charge
      ii. Naturally occurring
         1. Quartz
         2. Tourmaline
         3. Rochelle salt
   d. Synthetic:
      i. Lead Zirconate Titanate (PZT)
      ii. Many other proprietary crystal formulations
   e. Curie point: the temperature at which dipolar molecules are free to move within a crystal. Applying electrical plates across the material while it is heated to this temperature will align the molecules in an anisotropic fashion.
      i. NEVER HEAT STERILIZE A TRANSDUCER. Raising the temperature of the transducer above the Curie point will destroy the piezoelectric properties.

3. **Transducer construction and characteristics**
   a. Piezoelectric crystal
      i. Operating (resonance frequency)

1. Crystal thickness
2. Speed of sound in crystal material
3. Frequency characteristics

b. Backing material:
   i. Damping block: made of epoxy-like material. Serves to mechanically stop the "ringing" of the crystal.
   ii. Absorbs "reverse" ultrasound waves that are transmitted back to the crystal
   iii. Must have same acoustic impedance as crystal to prevent generating an echo from the backing/crystal interface
      1. Allows transducer to listen for returning echoes
      2. Limits length of emitted pulse which is important in determining axial resolution

c. Facing Material:
   i. A type of mechanical transformer that steps down the impedance changes between crystal and skin surface

d. Electrical connections:
   i. Insulation ring: absorbs energy generated by the sides of the crystal
   ii. Tuning coil: Removes excess electrical charge stored in crystal.
   iii. Electrical shield: protects the transducer from unwanted, spurious electric "noise" signals.
   iv. Electrical connectors: link the transducer crystal with the system electronics. Generally consist of a pair of very thin wires, one carries charge to transducer and one carries echo signal away from transducer.

4. Frequency Bandwidth

a. Resonant frequency: the natural ringing frequency of a transducer crystal. It is determined by the crystal thickness (T_c) and propagation velocity in the type of crystal used.
   i. Formula: $F_r = V/2T_c$

b. Bandwidth: the range of frequencies emitted by a transducer. It is the difference between the highest and lowest frequency emitted.

c. Q factor: Quality factor. A measure of "clean" beam frequency.

Beam Geometry

1. Factors Affecting Beam Geometry

a. Crystal diameter
b. Frequency bandwidth
c. Attenuation
d. Velocity of propagating medium (transducer material)
e. Huygen's principle

2. **Beam geometry**
    a. Focused vs. unfocused beams
    b. Near field (Fresnel zone)
    c. Far field (Fraunhofer zone)
    d. Transition zone
    e. Focused beams
        i. Mechanical focusing
        ii. Electronic focusing
        iii. Focal length

5. **Axial resolution**
    a. Definition: the ability to discriminate two point reflectors along the axis of the ultrasound beam
    b. Dependence on spatial pulse length/pulse duration
        i. Short pulse length = better resolution
            1. Number of waves per pulse
            2. Wavelength of each wave; (inversely proportional to frequency)
    c. Effect of frequency change:
        i. 3.5MHz transducer; $\lambda = V/F = 1{,}540 \div 3{,}500{,}000 = .44$mm/wave
        ii. 5.0MHz transducer: $\lambda = V/F = 1{,}540 \div 5{,}000{,}000 = .31$mm/wave

6. **Spatial pulse length**
    a. Physical length of an ultrasound pulse
    b. SPL = λc

7. **Lateral resolution**
    a. Definition: the ability to discriminate between tow point reflectors perpendicular to the beam axis
    b. Dependence on beam width
        i. Narrow beam = better resolution
    c. Effect of frequency change: higher frequency beams are less divergent = better lateral resolution
    d. Focusing