Ultrasonic Level Detection Technology
Definitions

- **Sound** - The propagation of pressure waves through air or other media
- **Medium** - A material through which sound can travel
- **Vacuum** - The absence of molecules in an area
- **Ultrasonic** - Concerned with ‘sound’ having a frequency $\geq 20,000$ Hz
Definitions

• Transducer - Any device that converts energy from one form to another.

• Range - The measured distance between a reference point and another point in space.

• Ranging - Measurement of the time from the transmission of a sound pulse to the reception of its echo.
Definitions

Blind Space - The amount of time required for the transducer vibration to decay to a level such that ultrasonic measurement of distance is possible

• Signal-to-Noise Ratio (S/N) - Ratio of signal amplitude to noise amplitude, usually expressed in decibels.
• Decibels - The measure of the intensity of sound.
  – 0 dB - The arbitrary value assigned the faintest audible sound that the human ear can hear.
  – 1 dB - The smallest difference between sounds that is humanly detectable.
  – 120 dB - The loudest sound that a human ear can tolerate.
# Definitions

<table>
<thead>
<tr>
<th>Source of the sound</th>
<th>Intensity Level (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet plane at 100 feet</td>
<td>140</td>
</tr>
<tr>
<td>Threshold of pain</td>
<td>120</td>
</tr>
<tr>
<td>Loud indoor rock concert</td>
<td>120</td>
</tr>
<tr>
<td>Siren at 100 feet</td>
<td>100</td>
</tr>
<tr>
<td>Auto interior, moving at 55 mph</td>
<td>75</td>
</tr>
<tr>
<td>Busy street traffic</td>
<td>70</td>
</tr>
<tr>
<td>Ordinary conversation at 20 in</td>
<td>65</td>
</tr>
<tr>
<td>Quite Radio</td>
<td>40</td>
</tr>
<tr>
<td>Whisper</td>
<td>20</td>
</tr>
<tr>
<td>Rustle of leaves</td>
<td>10</td>
</tr>
<tr>
<td>Threshold of hearing</td>
<td>0</td>
</tr>
</tbody>
</table>
Definitions

- Reflected - Energy is reflected or returned into the medium through which it has traveled when a sound wave encounters an interface between media of differing properties.

- Interface - A change in a transmission medium which affects the sound energy.

- Target - the surface (interface) we wish to measure.

- Level - the amount of material in a vessel.
Sound is energy moving through a medium, detected as variations in pressure.

Pressure variations move away from the source at the Sonic Velocity.

Surface moves in & out, changing the pressure in the material in front of it.

At any point in space which the energy reaches, the pressure changes at the same frequency as at the source.
Attributes of Sound

- Velocity - the speed at which sound travels through a particular medium (feet/min, MPH, etc.)
- Frequency - the rate at which the pressure variations of sound occur (Cycles/second = Hertz)
- Intensity - the difference in pressure between minimum and maximum (typically measured in decibels greater or less than some reference value)
Speed of Sound

• 1126 Feet per Second
  – @ 20°C Temperature
  – @ 50% Humidity
  – @ 1 Atmosphere
Speed of Sound

Air - 1126 ft per second @68°F (343.2 meters per second @20°C)

Air - 1089 ft per second @32°F (331.9 meters per second @0°C)

CO₂ - 850 ft per second @68°F (259.1 meters per second @20°C)

Carbon Tetrachloride Vapor - 475 ft per second @189°F (144.8 meters per second @87.2°C)
Basic Equation

Distance = Velocity x Time

Distance = 1126 ft/sec x 9 sec

Distance = 10,134 ft
Basic Equation Factors

- Distance - The distance from the source of sound to the sensor
- Velocity - The speed at which sound moves through the medium between the source and the sensor
- Time - The amount of time needed for the sound to move from the source to the sensor
Basic Equation Example

- We see lightning flash and count the seconds it takes for the thunder to reach us. We hear the thunder 9 seconds after the flash, so . . .
  - Distance = Velocity x Time
  - Distance = (1126 ft/sec)(9sec)
  - Distance = 10,134 ft
- The lightning occurred about 1.9 miles away.
Range Equation

\[ R = \frac{VT}{2} \]

- \( R \) = Range
- \( V \) = Velocity
- \( T \) = Time

Distance = \( \frac{\text{Velocity} \times \text{Time}}{2} \)

Range = \( \frac{(1126 \text{ ft./sec}) (50 \text{ msec.})}{2} = 28.15 \text{ ft.} \)
Range Equation Factors

• RANGE - The distance from the source of a signal to a target and back
• VELOCITY - The speed at which sound moves through the medium between the reference position and the target
• TIME - The amount of time needed for the sound to move from the Reference Position to the Target and back.
Range Equation Example

• I clap my hands at the base of a canyon and hear the echo from the opposite wall 4.5 seconds later. How far away is the canyon wall?

\[ R = \frac{\text{Velocity} \times \text{Time}}{2} \]

\[ R = \frac{(1126 \text{ ft / sec})(4.5 \text{ sec})}{2} \]

\[ R = 2,533.5 \text{ ft} \]

• The Wall is 2,534 feet away
Energy Transfer Requirements

- An acoustic pulse strong enough to overcome attenuation over the desired range
- A density change between the target material and the surrounding atmosphere
- An Echo which returns along the same path as the transmitted signal.
- An acceptable level for the signal-to-noise ratio
Causes of Energy Losses & Errors

- Distance
- Temperature
- Humidity
- Atmospheric Density
- Dust

- Vessel Filling
- Angle of Reflection
- Material Angle
- Material Properties
- Signal-To-Noise Ratio
The Inverse Square Law states that the signal intensity decreases inversely proportional to the square of the distance.

The signal returning from ‘B’ is 1/4 of that from ‘A’.

\[ I \propto \frac{1}{r^2} \]
Causes of Error

Temperature

• The speed of sound increases with increasing temperature at the rate of \(0.17\%/\text{C}^\circ\) (\(\approx 1\%\) for each 10 F\(^\circ\))
Causes of Error

Humidity

• An increase in relative humidity from 0% to 100% increases the speed of sound 0.44%
Causes of Errors

Density

• An increase in the atmospheric density decreases the speed of sound.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter Value</th>
<th>Effect on Speed of Sound</th>
<th>Effect on Calculated Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Up</td>
<td>Increase</td>
<td>Too Short</td>
</tr>
<tr>
<td></td>
<td>Down</td>
<td>Decrease</td>
<td>Too Long</td>
</tr>
<tr>
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<td>Increase</td>
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<td>Atmospheric Density</td>
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<td></td>
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<td>Increase</td>
<td>Too Short</td>
</tr>
</tbody>
</table>
Causes of Losses

Dust

• Dust has two main effects:
  – Absorbs acoustic energy
  – Decreases the apparent roughness of the surface of the target material
Causes of Losses

Vessel Filling

• Material passing through an acoustic beam will reflect or disperse the acoustic energy.
Causes of Losses

Angle of Reflection

Incident Ray

Reflected Ray

Incident Wave Front

Reflected Wave Front

False Path (long)

Weak Return

Lost Energy
Causes of Losses

Material Angle

- Level is subjective
- Surface is not horizontal
- Angle and shape change between fill and draw
- Comparison to tape may not be conclusive
Causes of Losses

Material Properties

• Acoustic Reflection Coefficient (ARC) is a function of:
  – Wavelength of the acoustic wave
  – Particle size and shape of the target material
  – Angle at which the acoustic wave strikes the target material.
Causes of Losses

Particle Size Relationship

• Particles smaller than \( \frac{1}{4} \) wavelength
  – Acoustically smooth and continuous surface
  – Strong return
  – Requires good aiming

• Particles equal to wavelength
  – Sound waves diffracts
  – Results can be total absorption

• Particles larger than \( \frac{1}{4} \) wavelength
  – Reflect and disperse the sound wave
  – Granular materials equal good echo
  – Round material equal weak return
Causes of Losses

Signal-To-Noise Ratio

- A ratio of the strength of the received signal to the strength of the background noise.

  This ratio must be greater than 1
Typical Ultrasonic System

- Signal Processor
- Transducer
- Medium
- Transmission path
- Target
The Signal Processor

- Provides the electrical energy for the transducer
- Controls the timing of events
- Performs the range calculation
- Scales the range signal to engineering units
- Provides for operator access
- Provides external output signals
The Transducer

- Converts electrical energy to acoustic energy
- Converts acoustic energy to electrical energy
- Provides directional control of energy
Transducer Attributes

• Frequency
• Efficiency
• Dispersion Angle
Transducer Frequency

- Larger transducers
  - resonate at lower frequencies
  - are useable at longer ranges
  - greater blind space due to larger mass

- Smaller transducers
  - resonate at higher frequencies
  - are useable on shorter ranges
  - smaller blind space due to less mass
Transducer Efficiency

Efficiency = \frac{\text{Power In}}{\text{Power Out}}

- Higher efficiency results in higher effective signal strength
- Lower efficiency can usually be overcome by increased power
Transducer Efficiency

- Factor That Affect
  - Mechanical construction
  - Frequency
  - Temperature
  - Pressure
3 dB decrease

12°

Beam Angle = 6° + 6° = 12°

Side Lobe (typical)
• The material through which the sound energy travels from the transducer to the target and back
• Should be clear of obstacles:
  – Framing or other vessel support hardware
  – Suspended solids or liquids in the medium
  – Material delivery and discharge systems
  – Sensor probes
  – Ladders
  – Bolt heads, rebar, welds, joint seams, etc.
Acoustic Energy

Striking An Interface Is

• Absorbed
  – and converted to heat

• Transmitted
  – through another medium

• Reflected
  – Back to the transducer
A Suitable Target

Surface Is Affected By

- Size and shape of the particles which make up the material. Angular shapes produce stronger echoes
- The angle of repose of the material
- The moisture content of the material
Transducers

- Tail Mass
- Piezoceramic Discs
- Head Mass
- Foam Disc
- TFE Film
<table>
<thead>
<tr>
<th>Operating Frequencies</th>
<th>Nominal Range</th>
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</thead>
<tbody>
<tr>
<td>14 KHz</td>
<td>100 Feet</td>
</tr>
<tr>
<td>22 KHz</td>
<td>50 Feet</td>
</tr>
<tr>
<td>24 KHz</td>
<td>75 Feet</td>
</tr>
<tr>
<td>43 KHz</td>
<td>25 Feet</td>
</tr>
</tbody>
</table>
### Transducers

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<tr>
<th>Operating Frequencies</th>
<th>Blind Space</th>
</tr>
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<tbody>
<tr>
<td>14 KHz</td>
<td>36 Inches</td>
</tr>
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<td>22 KHz</td>
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<tr>
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<tr>
<td>43 KHz</td>
<td>12 Inches</td>
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</tbody>
</table>
Transducers

Oscilloscope Trace of Typical Sound Echo

- Transmit Burst
- Blind Space
- Transducer Ringing
- Noise or False Target
- Noise or False Target
- Detected Target

Time = 0
<table>
<thead>
<tr>
<th>Enclosure Type</th>
<th>Temperature Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless Steel</td>
<td>230 ºF</td>
</tr>
<tr>
<td>CPVC</td>
<td>180 ºF</td>
</tr>
<tr>
<td>PVC</td>
<td>160 ºF</td>
</tr>
<tr>
<td>Flanged</td>
<td>160 ºF</td>
</tr>
</tbody>
</table>
Transducer

Dispersion Angle ($\theta$)

A cone of $x$ degrees angle, within which power is some specified proportion of the total.
Transducer Angle Example

- Dispersion angle has limited use in predicting performance.
- Smaller angles are usually more desirable.
Selecting a Transducer

• Should have a range greater than or equal to the height of the vessel
• Must be checked for compatibility with the material in the vessel
• Must be selected for the range of temperature that it will encounter
Vertical Location

- Determine the maximum fill level of the vessel
- Mount the transducer above the fill level by the length of the blind space
- Use a standpipe to raise the transducer if the fill point is too high
- Mount the transducer away from the wall
- Mount the transducer as far away from the filling point as possible to minimize the amount of material which flows through the acoustic beam
ultra-wave

Signal Processor

- Converts Energy
- Controls Timing
- Calculates Distance to Material
- Converts Distance to Engineering Units
- Provides External Outputs
- Provides for Operator Access
ultra-wave Applications

• Level Measurement
  – 1 to 16 Continuous Level Applications
• Differential Level Measurement
  – 1 to 8 DLD Applications
• Open Channel Flow Measurement
  – 1 to 4 OCM Applications
ultra-wave FUNCTIONAL BLOCK DIAGRAM
ultra-wave

System Configuration