**Ultrasonic Testing (UT):**
A nondestructive test method that uses high frequency sound energy to conduct examinations and make measurements.

**Sound:**
The mechanical vibration of particles in a medium (solid, liquid or gaseous).
From the duration of one oscillation $T$ the frequency $f$ (number of oscillations per second) is calculated:

$$f = \frac{1}{T}$$
The actual displacement \( a \) is termed as:

\[
a = A \cdot \sin \varphi
\]
<table>
<thead>
<tr>
<th>Frequency range (Hz)</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 20</td>
<td>Infrasound</td>
<td>Earthquake, whales</td>
</tr>
<tr>
<td>20 - 20.000</td>
<td>Audible sound</td>
<td>Speech, music</td>
</tr>
<tr>
<td>&gt; 20.000</td>
<td>Ultrasound</td>
<td>Bat, quartz crystal</td>
</tr>
</tbody>
</table>
Wave Propagation

- **Ball = atom**
- **Spring = elastic bonding force**

During one oscillation $T$ the wave front propagates by the distance $\lambda$:

**Wave equation:**

$$c = \frac{\lambda}{T} \quad \text{or} \quad c = \lambda \cdot f$$
Sound Propagation

- Longitudinal wave

Direction of oscillation

Direction of propagation

\[ \lambda \]
Sound Propagation

- Transverse wave

Direction of propagation

Direction of oscillation

\[ \lambda \]
Wave Propagation

- Longitudinal waves propagate in all kind of materials.
- Transverse waves only propagate in solid bodies.
- Due to the different type of oscillation, transverse waves travel at lower speeds.
- Sound velocity mainly depends on the density and Young’s modulus of the material.

<table>
<thead>
<tr>
<th>Material</th>
<th>Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>330</td>
</tr>
<tr>
<td>Water</td>
<td>1480</td>
</tr>
<tr>
<td>Steel, long</td>
<td>3250</td>
</tr>
<tr>
<td>Steel, trans</td>
<td>5920</td>
</tr>
</tbody>
</table>
Wave Propagation

Z = ρ * v

ρ: density

v: velocity

<table>
<thead>
<tr>
<th>Material</th>
<th>Longitudinal</th>
<th>Transverse (Shear)</th>
<th>Impedance Z</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in / us</td>
<td>mm / us</td>
<td>in / us</td>
</tr>
<tr>
<td>METALS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum 1100-0</td>
<td>0.248</td>
<td>6.229</td>
<td>0.121</td>
</tr>
<tr>
<td>Aluminum 2024-T4</td>
<td>0.251</td>
<td>6.375</td>
<td>0.124</td>
</tr>
<tr>
<td>Aluminum 6061-T6</td>
<td>0.248</td>
<td>6.299</td>
<td>0.124</td>
</tr>
<tr>
<td>Beryllium</td>
<td>0.507</td>
<td>12.878</td>
<td>0.350</td>
</tr>
<tr>
<td>Brass (70% Cu - 30% Zn)</td>
<td>0.172</td>
<td>4.369</td>
<td>0.083</td>
</tr>
<tr>
<td>Bronze (Phosphor 5%)</td>
<td>0.139</td>
<td>3.531</td>
<td>0.088</td>
</tr>
<tr>
<td>Copper (CP)</td>
<td>0.187</td>
<td>4.750</td>
<td>0.092</td>
</tr>
<tr>
<td>Gold</td>
<td>0.128</td>
<td>3.251</td>
<td>0.047</td>
</tr>
<tr>
<td>Hastelloy C</td>
<td>0.230</td>
<td>5.842</td>
<td>0.114</td>
</tr>
<tr>
<td>Hastelloy X</td>
<td>0.228</td>
<td>5.791</td>
<td>0.108</td>
</tr>
<tr>
<td>Inconel (Wrought)</td>
<td>0.308</td>
<td>7.823</td>
<td>0.119</td>
</tr>
<tr>
<td>Iron (Cast), Various Alloys</td>
<td>0.138-0.220</td>
<td>3.505-5.588</td>
<td>0.087-0.126</td>
</tr>
<tr>
<td>Lead (94Pb-6Sb)</td>
<td>0.085</td>
<td>2.159</td>
<td>0.032</td>
</tr>
<tr>
<td>Magnesium, Various Alloys</td>
<td>0.215-0.228</td>
<td>5.461-5.791</td>
<td>0.119-0.122</td>
</tr>
<tr>
<td>Monel</td>
<td>0.211</td>
<td>5.359</td>
<td>0.107</td>
</tr>
<tr>
<td>Nickel (CP)</td>
<td>0.222</td>
<td>5.639</td>
<td>0.117</td>
</tr>
<tr>
<td>Silver (0.99 Fine)</td>
<td>0.142</td>
<td>3.607</td>
<td>0.063</td>
</tr>
<tr>
<td>Steel 1020</td>
<td>0.232</td>
<td>5.893</td>
<td>0.128</td>
</tr>
<tr>
<td>Steel 4340</td>
<td>0.230</td>
<td>5.842</td>
<td>0.128</td>
</tr>
<tr>
<td>Steel, CRES 300 Series</td>
<td>0.221-0.226</td>
<td>5.613-5.740</td>
<td>0.120-0.123</td>
</tr>
<tr>
<td>Steel, CRES 400 Series</td>
<td>0.212-0.237</td>
<td>5.385-6.020</td>
<td>0.118-0.132</td>
</tr>
<tr>
<td>Titanium, 6Al-4V</td>
<td>0.243</td>
<td>6.172</td>
<td>0.130</td>
</tr>
<tr>
<td>Zircaloy</td>
<td>0.186</td>
<td>4.724</td>
<td>0.093</td>
</tr>
<tr>
<td>Zirconium</td>
<td>0.183</td>
<td>4.648</td>
<td>0.089</td>
</tr>
</tbody>
</table>
Wave Propagation

- Behaviour at an interface:

- Medium 1
  - Incoming wave
  - Reflected wave

- Medium 2
  - Transmitted wave

Interface
Ultrasound Generation

- Ultrasound is generated with a transducer.

A piezoelectric element in the transducer converts electrical energy into mechanical vibrations (sound), and vice versa.

The transducer is capable of both transmitting and receiving sound energy.
Ultrasound Generation

Piezoelectric Effect (I)

Piezoelectrical Crystal (Quartz)

Battery

PZT
Ultrasound Generation

Piezoelectric Effect (II)

The crystal gets thicker, due to a distortion of the crystal lattice
Ultrasound Generation

Piezoelectric Effect (III)

The effect inverses with polarity change
Ultrasound Generation

Piezoelectric Effect (IV)

An alternating voltage generates crystal oscillations at the frequency $f$.

Sound wave with frequency $f$
Transmitted sound waves are divided into regions designated as the “near field” and “far field”.

Extensive “noise” in the near field where sound originates – this makes it difficult to accurately evaluate flaws in this region.

Desire to have the detection area in the far field so no flaws are missed during an inspection.
• Ultrasonic testing is a very versatile inspection method, and inspections can be accomplished in a number of different ways.

• Ultrasonic inspection techniques are commonly divided into three primary classifications.

  – **Pulse-echo and Through Transmission**
    (Relates to whether reflected or transmitted energy is used)

  – **Normal Beam and Angle Beam**
    (Relates to the angle that the sound energy enters the test article)

  – **Contact and Immersion**
    (Relates to the method of coupling the transducer to the test article)
In pulse-echo testing, a transducer sends out a pulse of energy and the same or a second transducer listens for reflected energy (an echo).

Reflections occur due to the presence of discontinuities and the surfaces of the test article.

The amount of reflected sound energy is displayed versus time, which provides the inspector information about the size and the location of features that reflect the sound.
Test Techniques - Pulse-Echo

Digital display showing signal generated from sound reflecting off back surface.

Digital display showing the presence of a reflector midway through material, with lower amplitude back surface reflector.

The pulse-echo technique allows testing when access to only one side of the material is possible, and it allows the location of reflectors to be precisely determined.
Two transducers located on opposing sides of the test specimen are used. One transducer acts as a transmitter, the other as a receiver.

Discontinuities in the sound path will result in a partial or total loss of sound being transmitted and be indicated by a decrease in the received signal amplitude.

Through transmission is useful in detecting discontinuities that are not good reflectors, and when signal strength is weak. It does not provide depth information.
Test Techniques – Through-Transmission

Digital display showing received sound through material thickness.

Digital display showing loss of received signal due to presence of a discontinuity in the sound field.
Weld inspection

\[ a = s \sin \beta \]
\[ a' = a - x \]
\[ d' = s \cos \beta \]
\[ d = 2T - t' \]

\( \beta \) = probe angle
\( s \) = sound path
\( a \) = surface distance
\( a' \) = reduced surface distance
\( d' \) = virtual depth
\( d \) = actual depth
\( T \) = material thickness

Work piece with welding
Lack of fusion
**Test Techniques – Immersion testing**

- **Couplant**: material used to facilitate the transmission of ultrasonic energy from the transducer into the test specimen.
The longitudinal velocity in aluminum is 0.65 cm/µs. Using a 2.25 MHz transducer, what is the wavelength of sound produced in the material? What is the minimum size flaw detected?

\[ \lambda = \frac{c}{f} = \frac{6420 \text{ m/s}}{2.25 \cdot 10^6 \text{ cycles/s}} = 2.85 \text{ mm} \]

*Rule of Thumb: A discontinuity must be >1/2 the wavelength to be detected (influences transducer frequency selected). So, for the example flaws must be greater than 1.42 mm using 2.25MHz transducer.
Advantage of Ultrasonic Testing

- Sensitive to small discontinuities both surface and subsurface.
- Depth of penetration for flaw detection or measurement is superior to other methods.
- Only single-sided access is needed when pulse-echo technique is used.
- High accuracy in determining reflector position and estimating size and shape.
- Minimal part preparation required.
- Electronic equipment provides instantaneous results.
- Detailed images can be produced with automated systems.
- It has other uses such as thickness measurements, in addition to flaw detection.
Limitations of Ultrasonic Testing

- Surface must be accessible to transmit ultrasound.
- Skill and training is more extensive than with some other methods.
- Normally requires a coupling medium to promote transfer of sound energy into test specimen.
- Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect.
- Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.
- Linear defects oriented parallel to the sound beam may go undetected.
- Reference standards are required for both equipment calibration, and characterization of flaws.
Some Standards relating to Ultrasonic Testing

- American Society for Testing and Materials (ASTM):
  - ASTM E114 - Standard Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method.
  - ASTM E164 - Standard Practice for Ultrasonic Contact Examination of Weldments.
  - ASTM E213 - Standard Practice for Ultrasonic Examination of Metal Pipe and Tubing.
  - ASTM E273 - Standard Practice for Ultrasonic Examination of the Weld Zone of Welded Pipe and Tubing.
  - ASTM E588 - Standard Practice for Detection of Large Inclusions in Bearing Quality Steel by the Ultrasonic Method.
Ultrasonic Testing Video

Non-destructive Testing
Ultrasonic Examination

https://www.youtube.com/watch?v=UM6XKvXWVFA
References
