



Ultrasonic Testing Classroom Training Book, Second Edition

Errata – 1st Printing 02/15

The following text corrections pertain to the second edition of the *Ultrasonic Testing Classroom Training Book*. Subsequent printings of the document will incorporate the corrections into the published text.

The attached corrected pages apply to the first printing. In order to verify the print run of your book, refer to the copyright page. Ebooks are updated as corrections are found.

Page	Correction
5	<p>Under Eq. 1: V = the velocity of sound in the material being tested (most often expressed in kilometers <u>per second</u>)</p> <p>Eq. 2 should be $\lambda = V/f$</p> <p>Eq. 3 should be $f = V/\lambda$</p>
6	<p>Table 1: The columns under Shear Waves should show shear-wave velocity represented by V_S instead of V_L.</p> <p>The speed of longitudinal waves (V_L) in air should be: 13×10^3 in./s and 330 m/s.</p>
7	<p>Examples of exponents should be superscripted as follows: x^2, 2^3, and 10^4.</p>
52	<p>The lead-in to Eq. 2 and the equation should be changed as follows: With reference to Equation 2 (Chapter 1), λ can be replaced with V/f, so this formula can be rewritten as:</p> <p>(Eq. 2)</p> $L = \frac{D^2 f}{4V}$
53	<p>The lead-in to Eq. 4 and the equation should be changed as follows: Again, by substituting V/f for λ, this equation becomes:</p> $\sin \theta = 1.22 \frac{V}{Df}$

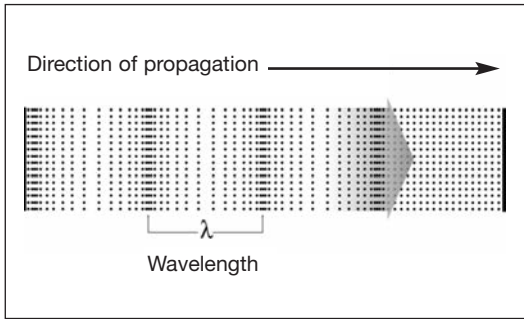


Figure 1: Sound wave moving through a material.

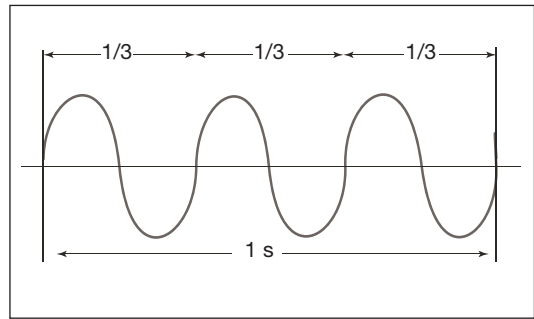


Figure 2: Length of sound wave from trough to trough. Three periods per second equals three cycles per second, or 3 Hz.

the wave. It is the energy of the wave that moves through the material. This concept is illustrated in Figure 1.

If the length of a particular sound wave is measured from trough to trough, or from crest to crest, the distance is always the same, as shown in Figure 2. This distance is known as the wavelength. The time it takes for the wave to travel a distance of one complete wavelength is the same amount of time it takes for the source to execute one complete vibration.

The velocity of sound V is given by Equation 1:

$$(Eq. 1) \quad V = \lambda \times f$$

where

λ = the wavelength of the wave (most often expressed in millimeters)

V = the velocity of sound in the material being tested (most often expressed in kilometers per second)

f = the frequency of the wave (most often expressed in megahertz)

By performing a few simple algebraic manipulations to this formula, we can get the formula for wavelength (λ) and frequency (f) as shown in Equations 2 and 3.

$$(Eq. 2) \quad \lambda = V / f$$

$$(Eq. 3) \quad f = V / \lambda$$

Table 1 shows typical sound velocities for materials that may be seen when performing ultrasonic inspections.

Table 1: Nominal material sound velocities.

MATERIAL	LONGITUDINAL WAVES		SHEAR WAVES	
	$V_L = 10^3 \text{ in./s}$	$V_L = \text{m/s}$	$V_s = 10^3 \text{ in./s}$	$V_s = \text{m/s}$
AIR	13	333	-----	-----
ALUMINUM, GALVANIZED	246	6250	122	3100
BARIUM TITANATE	217	5500	-----	-----
BERYLLIUM	504	12 800	343	8710
BRASS (NAVAL)	174	4430	83	2120
BRONZE (P-5%)	139	3530	88	2230
CAST IRON	177	4500	94	2400
COPPER	183	4660	89	2260
GLYCERINE	76	1920	-----	-----
LEAD, PURE	85	2160	28	0700
MAGNESIUM, AM 35	228	5790	122	3100
MOLYBDENUM	248	6290	132	3350
NICKEL	222	5630	117	2960
PLASTIC (ACRYLIC RESIN-PLEXIGLASS)	105	2670	44	1120
POLYETHYLENE	60	1530	-----	-----
QUARTZ, FUSE	233	5930	148	3750
SILVER	142	3600	63	1590
STEEL	230	5850	127	3230
STAINLESS 302	223	5660	123	3120
STAINLESS 410	291	7390	118	2990
TIN	131	3320	66	1670
TITANIUM (T1 150A)	240	6100	123	3120
TUNGSTEN	204	5180	113	2870
WATER	59	1490	-----	-----
ZINC	164	4170	95	2410

Note: Values are approximate and may vary depending on the source of data; multiplying a number N by $10^3 = N \times 1000$.

Order of Mathematical Operations

A useful acronym for remembering the order of mathematical operations is PEMDAS, which stands for parentheses, exponents, multiplication, division, addition, and subtraction.

- **Parenthesis** – groupings of numbers and/or variables using () or []. If parentheses are enclosed in other parenthesis, simplify the inside sets first and then move outward.
- **Exponents** – are performed next (unless inside parentheses). If the formula contains multiple exponents, these are performed from left to right. Examples include x^2 , 2^3 and 10^4 .
- **Multiplication and division** – when outside of parentheses, multiplication and division are of equal importance and performed from left to right.
- **Addition and subtraction** when outside of parentheses, addition and subtraction are of equal importance and performed from left to right.

Trigonometry

As shown in Figure 3, the right triangle is an essential part of the shear wave formulas you will be using to calculate the location of discontinuities. These formulations are based on sound path distance. Snell's law is used to calculate incident and refracted angles using the velocities of two dissimilar materials and is another reason to be familiar with trigonometry. Here is a brief overview of trigonometry based on the relationship of angles and sides as it relates to shear wave testing.

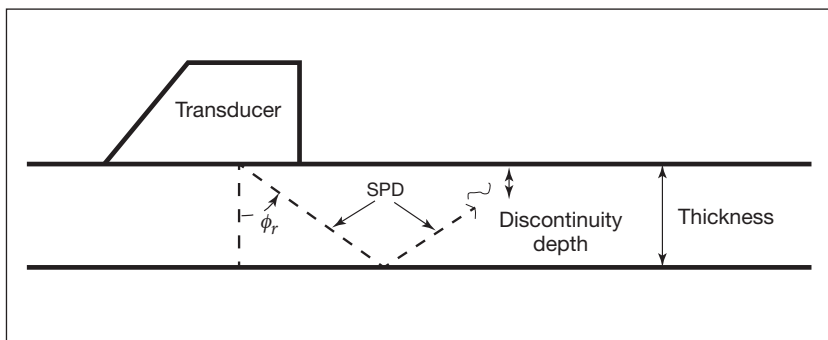


Figure 3: Sound-path distance (SPD).

Right Triangles

Refer to Figure 4 as you review the following:

1. All triangles are made up of three angles and three corresponding sides.
2. The sum of the three angles totals 180° .
3. In a right triangle, one angle is equal to 90° and, as a result, the sum of the other two angles must total 90° .
4. The length of a side is directly proportional to its corresponding angle; the greater the angle, the greater the length of its corresponding side.

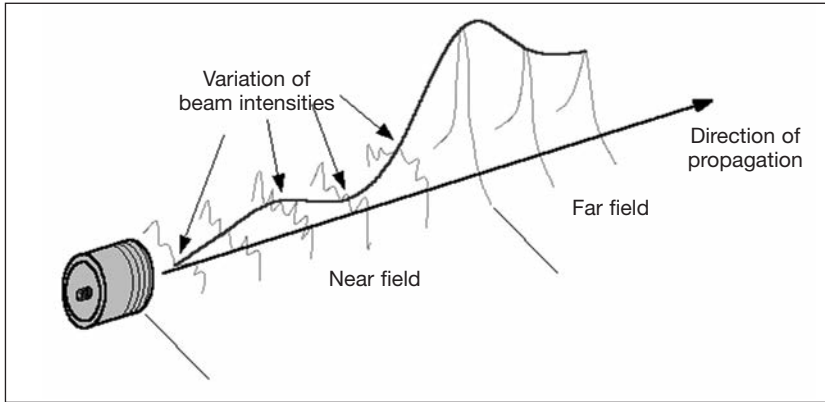


Figure 3: Ultrasonic wave field in front of a disk-shaped transducer.

waves, which emanate from the periphery of the crystal face, produce side-lobe waves that interfere with the plane front waves. This causes patterns of acoustical maximums and minimums where they cross, as shown in Figure 3.

The effect of these acoustical patterns in the near-field zone varies during an ultrasonic test. However, if the technician has proper knowledge of the near field, the correct reference block can be scanned and correlated with the indications from the test.

The length of the near field is dependent on the diameter of the transducer and the wavelength of the ultrasonic beam, and may be computed as:

$$(Eq. 1) \quad L = \frac{D^2}{4\lambda}$$

where

L = the length of the near field

D = the diameter of the transducer

λ = the wavelength of the ultrasonic energy

With reference to Equation 2 (Chapter 1), λ can be replaced with V/f , so this formula can be rewritten as:

$$(Eq. 2) \quad L = \frac{D^2 f}{4V}$$

where

V = the sound velocity of the material

f = the frequency of the transducer

Since the wavelength of ultrasonic energy in a particular material is inversely proportional to the frequency, the length of the near field in a particular material can be shortened by lowering the frequency.

Far Field

In the zone farthest from the transducer, the only effect of consequence is the spreading of the ultrasonic beam and the natural attenuation effect of the material. The highest sound intensity occurs at the end of the near field/beginning of the far field. From that point on, the beam intensity is reduced by the attenuation characteristics of the material in which it is traveling and by beam spread.

Beam Spread

Fraunhofer diffraction causes the beam to spread starting at the end of the near field. At this distance, the beam originates at the center of the radiating face of the transducer and spreads outward, as shown in Figure 4.

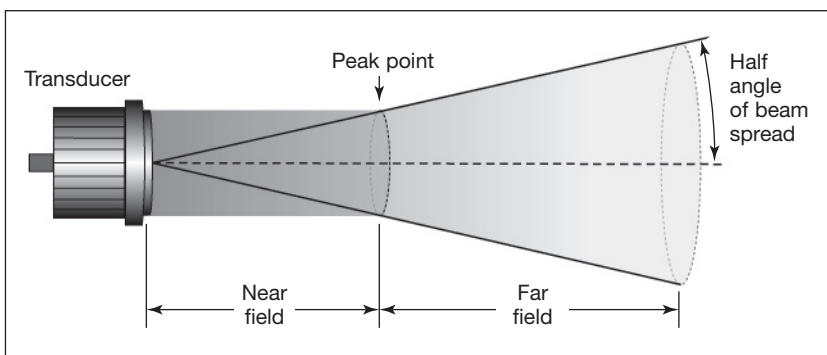


Figure 4: Beam spread computation.

The degree of spread may be computed as:

$$(Eq. 3) \quad \sin \theta = 1.22 \frac{\lambda}{D}$$

where

θ = the half angle of spread

λ = the wavelength of the ultrasonic energy

D = the diameter of the transducer

Again, by substituting V/f for λ , the equation becomes:

$$(Eq. 4) \quad \sin \theta = 1.22 \frac{V}{Df}$$

where

f = the frequency of the transducer

V = the sound velocity in the material

Calculations of the near field and far field are illustrated in Figure 5.



Ultrasonic Testing Classroom Training Book second edition

Errata – second printing 04/16

The following text correction pertains to the second edition of the *Ultrasonic Testing Classroom Training Book*. Subsequent printings of the document will incorporate the corrections into the published text.

The attached corrected page applies to the second printing 04/16. In order to verify the print run of your book, refer to the copyright page. Ebooks are updated as corrections are found.

Page	Correction
61	The figure 14 caption “Spatial resolution” should be “Near surface resolution.”
127–128	At the bottom of page 127 and top of 128, the two instances of “sound velocity” should be “acoustic impedance.”

Catalog #1642
Book printed 04/16
Errata created 07/17

Even transducers of the same size, frequency, and material by the same manufacturer do not always produce identical indications on a given display screen. A transducer's sensitivity is rated by its ability to detect a given size flat-bottom hole at a specific depth in a standard reference block.

Resolution

The *resolution* or *resolving power* of a transducer refers to its ability to separate the echoes from two reflectors close together in time; for example, the front-surface echo and an echo from a small discontinuity just beneath the surface. The time required for the transducer to stop *ringing* or vibrating after having been supplied with a long voltage pulse is a measure of its near-surface resolving power. Long tails or wave trains of sound energy from a ringing transducer cause a wide, high amplitude echo from all reflectors in the sound path, including the entry surface.

As illustrated in Figure 14(a), a small discontinuity just beneath the surface is easily masked by the ringing signal of the initial pulse. Figure 14, in general, shows that even reflectors at a greater distance are not displayed distinctly due to the same issue of too long a pulse length applied to the transducer. Figure 15 displays additional examples of poor versus good resolution in the far field.

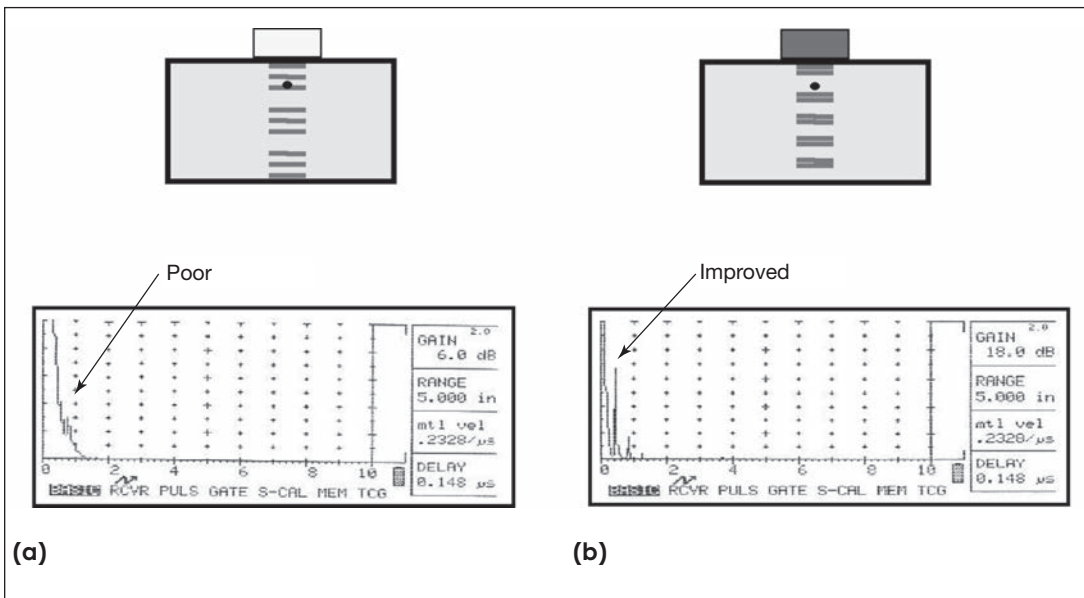


Figure 14: **Near surface** resolution: (a) poor resolution; (b) improved signal.

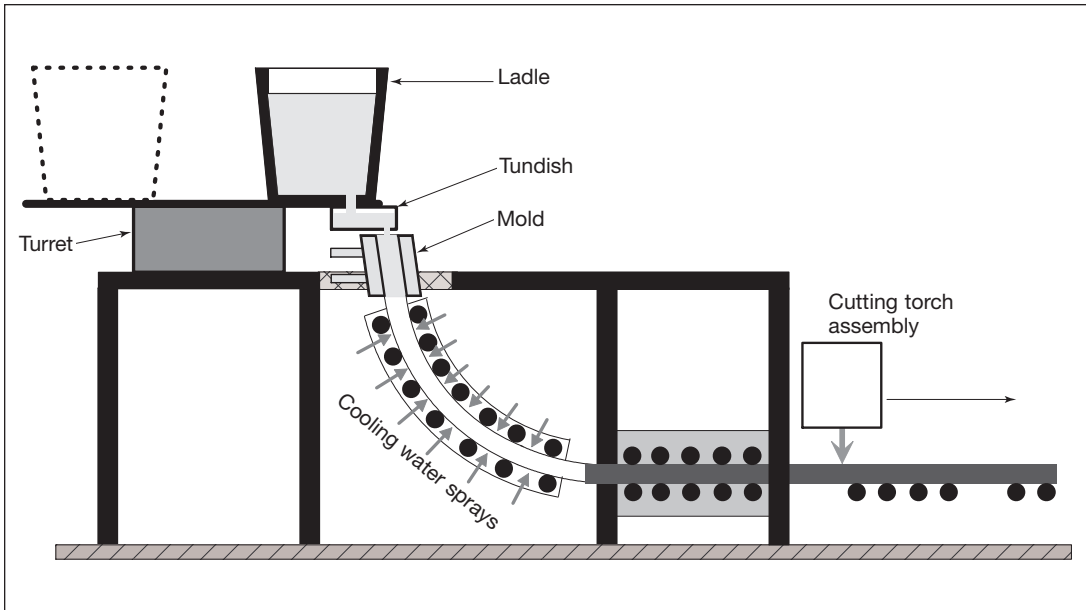


Figure 2: Continuous caster.

through the curved series of rollers, as shown. After the dummy bar passes through the final set of rollers, it is removed, leaving a continuous length of new steel extending from the mold to the cutting area beyond the last set of rollers.

During the entire casting process, the steel is sprayed with water to control the *solidification process*. As with ingots, the solidification process occurs from the outside inward, so the steel starting down the caster has a solid outer shell with a molten core. As the process continues, the steel solidifies completely and is rolled to the desired thickness as it passes through the final set of rollers. Once the steel exits the final rollers, a cutting torch system clamps to the new slab, cutting it to the desired length.

Discontinuities in Steel

Inherent discontinuities in the ingot-casting and continuous-casting processes are similar to those of other castings and include segregation, nonmetallic inclusions, shrinkage voids, cracks, and pipe.

Segregation occurs when individual elements either are not fully mixed in the heat or separate during the cooling process. Segregated elements do not have the same sound velocity as the parent metal, but unless the areas of segregation are relatively large, they cannot be easily detected ultrasonically. *Nonmetallic inclusions*, such as slag and other contaminants, are generally larger in size than segregations and can be more easily detected using ultrasonic testing.

Shrinkage voids and *cracks* are both good reflectors of sound and can be detected ultrasonically much more readily than segregation due to the sharp edges of the resulting voids and the large change in **acoustic**

impedance between the void and the metal. Because the entrapped gas tends to form rounded tubes with smoother sides, *pipe* does not result in as sharp a reflector as *shrinkage* and *shrink cracks*. But because of the change in **acoustic impedance** between the gas and the metal, it too can be easily found ultrasonically.

Slabs and Billets

Because of their size, *slabs* and *billets* must be processed to reduce them to a manageable thickness. This is done in hot-rolling mills where the heated slab or billet is repeatedly passed through correspondingly tighter rollers. As the slab or billet is rolled, it increases in length, resulting in a longer, thinner shape. During this process, the metal grains in the steel are elongated in the direction of rolling, as are most discontinuities. Depending on the intended use of the steel, the product may be cut to length between rolling passes to make handling more manageable.

Plate and Sheet

The rolling process permits slabs and billets to be reduced in thickness into plates, and, if the process is continued, the plates can be rolled into *sheets*. Since the thinning process continually elongates the product form, rolling sheet steel results in a very long product. To reduce the physical size of the forming area and to make handling easier, the sheet is often formed into a coil. These coils can then be transported, stored for additional forming processes, or sent back through the same rollers set at closer tolerances to further reduce the thickness of the sheet. During the rolling operation, several types of process discontinuities can occur, as shown in Figure 3.

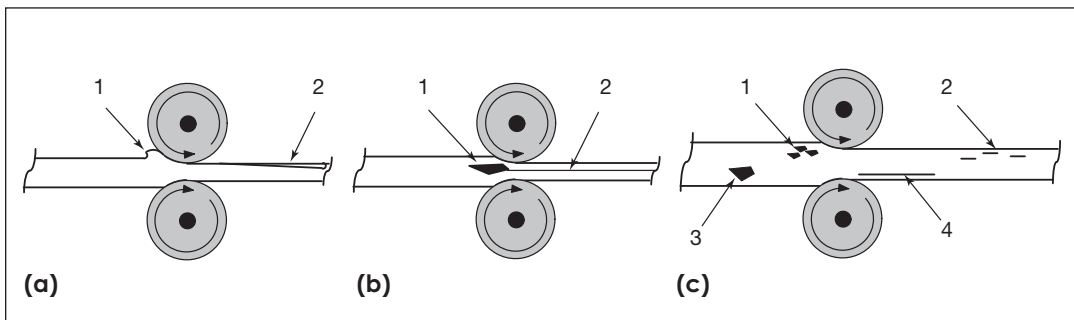


Figure 3: Rolling discontinuities: (a) rolling lap; (b) centerline delamination; (c) segregation and inclusion laminations.

Discontinuities in Plate and Sheet

One such discontinuity is a *rolling* or *surface lap*, shown in Figure 3(a). This occurs when some of the metal humps up in front of one of the rolls (1) and then is folded back over the unrolled sheet and pulled through the rollers. This results in an elongated sliver of steel that has been pressed back into the surface of the plate (2). The lap may be