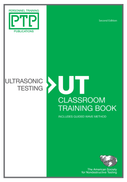

Ultrasonic Testing Classroom Training Book, Second Edition

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

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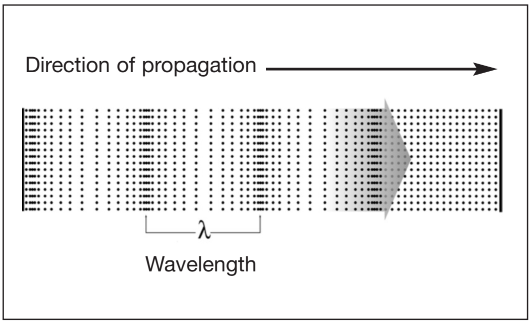

Figure 1: Sound wave moving through a material.

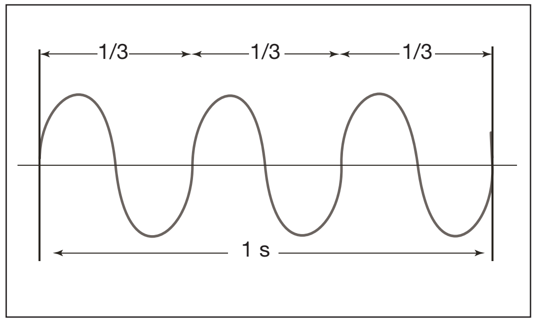

Figure 2: Length of sound wave from trough to trough. Three periods per second equals three cycles per second, or 3 Hz.

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) $$V = \lambda \times f$$

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) $$\lambda = V / f$$

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

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 in./s	V_L = m/s	V_S = 10^3 in./s	V_S = 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; multipying 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.

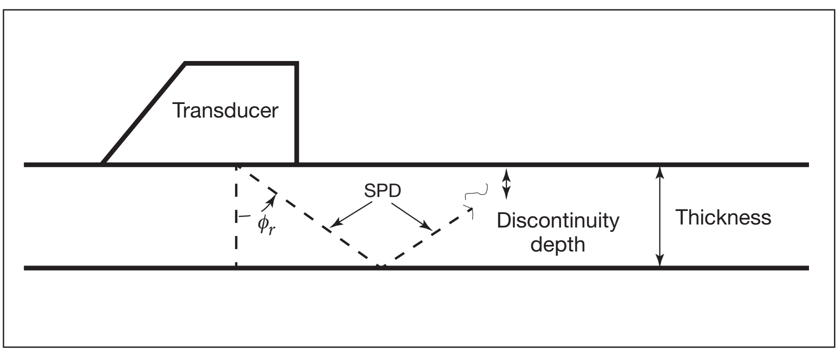

Figure 3: Sound-path distance (SPD).

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.

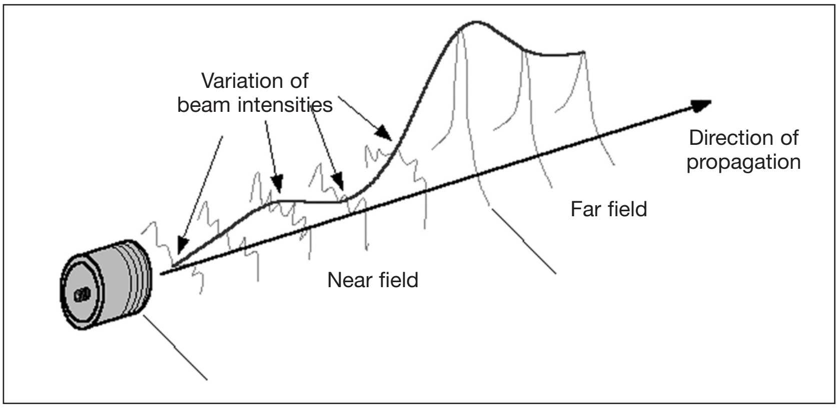

Figure 3: Ultrasonic wave field in front of a disk-shaped transducer.

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) $$L = \frac{D^2}{4\lambda}$$

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) $$L = \frac{D^2 f}{4V}$$

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.

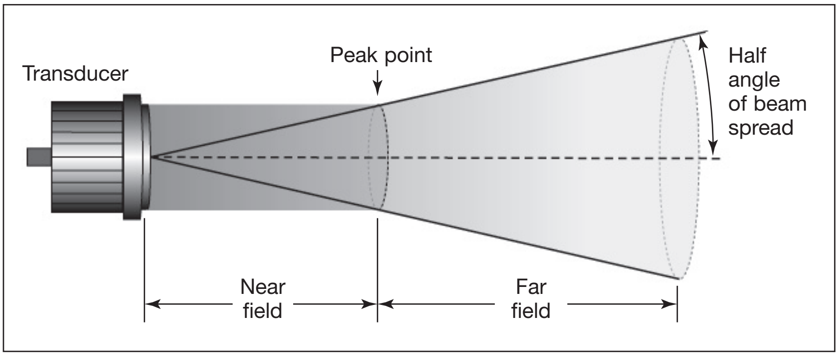

Figure 4: Beam spread computation.

The degree of spread may be computed as:

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

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) $$\sin\theta = 1.22\frac{V}{Df}$$

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.