ASNT Industry Handbook: Aerospace NDT

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The following text correction pertains to the *ASNT Industry Handbook: Aerospace NDT*. 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
9.6	Equation 9.6 has been replaced with the following: $T = \frac{2\,Z_2}{Z_2 + Z_1}$
10.21	Figure 21: Labels at the bottom of the figure are reversed. They should read “Source-to-object distance” and “Object-to-detector distance.

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Ultrasonic Transmission and Reflection

The transmission and reflection of ultrasound in media and across interfaces is fundamental to its application in nondestructive testing. Within a material and at interfaces, the ultrasound maintains continuity of particle velocity, acoustic pressure, and phase. These conditions, particularly at boundaries, determine the amplitude and direction of the transmitted and reflected waves.

The velocity and wavelength of ultrasound play important roles in the selection of ultrasonic techniques and applications. As the ultrasonic frequency increases, the wavelength becomes shorter and smaller features can be detected. But as the frequency increases, the smaller wavelength will increase attenuation due to scatter of the ultrasound and the inspection depth becomes limited. Attenuation of the sound pressure amplitude of a plane wave (in two dimensions) can be represented:

(5) $$A = A_0 e^{-ad}$$

where A is the end pressure amplitude, A_o is the initial pressure amplitude, α is the attenuation coefficient (in nepers per unit distance), and d is the distance traveled. For travel over a distance d, the attenuation is:

(6) $$\alpha d = \ln \frac{A_0}{A}$$

In practice it is useful to use a logarithmic measurement to express reduction (attenuation) or increase (gain) of a signal. The decibel (dB) unit, named after Alexander Graham Bell, is based on a logarithmic ratio:

(7) $$1\ \text{dB} = 10 \log_{10} \frac{I}{I_0}$$

where I_0 and I are the initial and final intensity or power. Intensity or power is proportional to the square of the potential V (volts) or pressure amplitude A. This gives the conversion:

(8) $$10 \log_{10} \frac{I}{I_0} = 10 \log_{10} \frac{A^2}{A_0^2} = 20 \log_{10} \frac{A}{A_0}$$

where A_o is initial signal amplitude and A is the final signal amplitude.

The dB measure of attenuation is useful for the range of values that occur in ultrasonics. A change of 6 dB in the amplitude of a signal represents a change by about a factor of 2, and a change of 20 dB in amplitude represents a change by a factor of 10. Table 3 shows the attenuation fraction and the dB value that corresponds to it. Measured in decibels, the neper is 8.7 dB. Figure 5 is a notional diagram showing the effect of frequency on the attenuation of ultrasound. When the frequency is low, the wavelength may be larger than small features in a material such as the crystalline grains in metals, so attenuation is low. As the frequency increases, wavelength becomes smaller and these ultrasound-to-grain interactions will increase attenuation due to scatter.

The ability of ultrasound to detect features during inspection is a function of the changes in acoustic impedance at interfaces. This forms the basis for the vast majority of ultrasonic inspection techniques used for discontinuity detection. Transmission and reflection of ultrasonic pressure across interfaces are given by:

(9) $$T = \frac{2 Z_2}{Z_2 + Z_1}$$

and

(10) $$R = \frac{R_t}{R_0} = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

where A_t is transmitted pressure amplitude, R is the reflection coefficient (ratio of reflected R_t to initial R_0 signal amplitude), T is the transmission coefficient (ratio of transmitted to initial signal amplitude), and Z_1 and Z_2 are the acoustic impedances of materials 1 and 2 at an interface (Krautkrämer 1990, 15-16). Acoustic impedance is the product of the acoustic velocity and density of the medium through which the ultrasonic signal is propagating. Table 4 lists interface transmission and reflection coefficients and their corresponding decibel values for several possible aerospace inspection interfaces. The table shows that, because of the large change in acoustic impedance at an air interface, it is difficult to couple sound into air. The high impedance mismatch between air and most materials to be inspected results in low transmission coefficients. This, in turn, allows only a small fraction of the signal intensity to be transmitted across the interface. Therefore, immersion or contact ultrasonic testing is preferred unless a noncontact and dry condition is strictly specified. The velocity of material particles at the interface are equal, so

Figure 5. Notional attenuation of ultrasound with frequency.

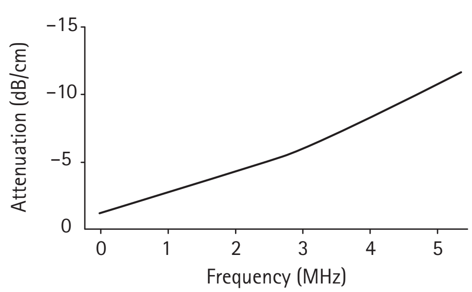


Table 3. Attenuation and decibel value.

Relative Ultrasonic Signal Amplitude	Attenuation (dB)
1	0
0.5	6
0.25	12
0.125	18
0.1	20
0.03	30
0.01	40
0.001	60
0.0001	80
0.00001	100

Magnification improves resolution and reveals details. Unfortunately, as the magnification increases, edge definition may become worse due to geometric unsharpness caused by a large X-ray focal spot. Therefore, the focal spot size must be kept small such that the ensuing geometric unsharpness is kept lower than any unsharpness contribution from the image detector. The resolution of the X-ray film or detector/image plate determines the size of the focal spot below which unsharpness is negligible.

In some cases, especially digital radiologic testing with digital detector arrays, microfocus X-ray may be required. These sources can easily enlarge features by factors of 20 or more for either film or nonfilm techniques.

Geometric Image Unsharpness (Geometry and Source Size)

The term image unsharpness recognizes that there is always some blurring in the image. Specifically, geometric image unsharpness U_g is due to the finite size of the source of radiation and the geometric magnification. Figure 21 shows how geometric unsharpness is formed. The distance on the detector over which an edge of a feature is spread is known as the penumbral shadow or the geometrical unsharpness. The equation to determine unsharpness is:

(16)
$$U_g = \text{ODD} \times \frac{f}{\text{SOD}}$$

where f is the diameter of the focal spot at its widest, ODD is the object-to-detector distance, and SOD is the source-to-object distance.

Because the X-ray source always has a finite size, geometric unsharpness or image blur will always occur. The magnitude of geometrical unsharpness is directly proportional to the X-ray source size. The only way to reduce the image blur for a fixed radiologic setup is to use a machine with a smaller focal spot.

Total Image Unsharpness (Including Detector Contribution)

In addition to geometric unsharpness, total unsharpness of the radiologic image is also affected by the characteristics of the X-ray film, digital detector array, image plate (in computed radiologic testing), or radioscopic imager. Typically, whichever unsharpness contribution is greater will control the total image unsharpness. In standards for film and nonfilm radiologic media are detailed requirements for the maximum geometric unsharpness as a function of inspected object thickness (ASTM E 1742, 2012a). These limits are extended in digital detector arrays and computed radiologic testing to apply to the total image unsharpness, incorporating the effects of the image medium. Historically, this was first an issue with florescent screens in film casettes, which resulted in unsharpness contributions because of the larger detector (ASTM 1999).

Typically, for film, the total unsharpness requirements only limit the maximum geometrical magnification that can be used in a radiologic test

Figure 20. Geometric magnification.

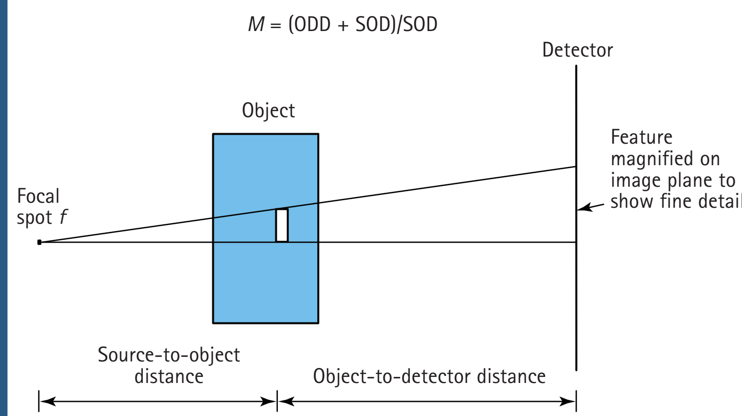
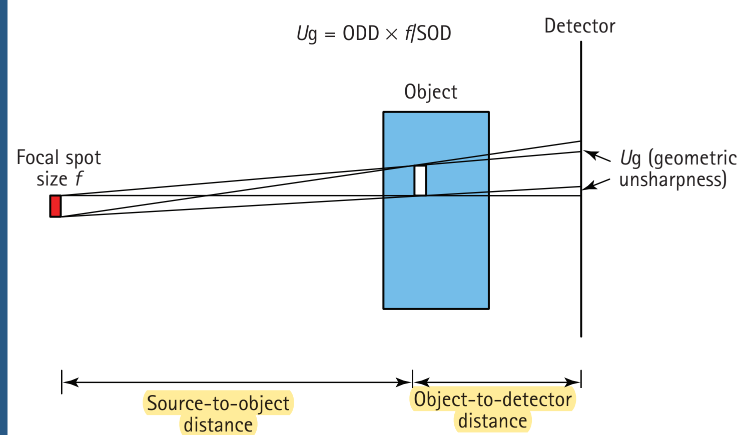


Figure 21. Geometric unsharpness.



because of the finite focal spot size. With the relatively high resolution capability of film, many inspections may be performed with no magnification, so only the film's resolution characteristics need to be considered. If more magnification is needed than is allowed, a smaller focal spot size or another X-ray tube may be selected.

For nonfilm radiologic techniques (computed radiologic testing and radioscopy), managing the total image unsharpness is especially important as the detector contribution is often significant and must be considered in addition to the geometric unsharpness. In addition, to measure the sizes of small pores accurately in aerospace structures, one must ensure that there are enough image pixels within the indication. This resolution will routinely require up to 5× magnification, so a calculation of the geometrical and total unsharpness will be important.

In any given situation, the geometric unsharpness that can be tolerated sets the lower limit for the adjustable parameters, such as focal spot size,