Chapter 7

Equipment Calibration

INTRODUCTION

The equipment used in ultrasonic testing involves electronic and mechanical devices working together to accurately capture the way ultrasonic waves interact with various features of test materials. Ultrasound interaction within a given material is analyzed by measuring the strength and the nature of returning waves. Location of reflectors is deduced by knowing the direction of the wave's propagation and the time elapsed in the wave's travel from the sending source to the receiving device. The speed of sound in the test object must be known for accurate distance estimations. For simple test object geometries such as plate materials, the ultrasonic testing instrument can be used to interpret features such as thickness and presence of major discontinuities. As the geometric complexity of test objects increases, interpretation of detected ultrasonic wave signals becomes more difficult. To interpret results precisely, the fundamental characteristics of the ultrasonic testing system must be known.

Equipment calibration is the process of repeatedly verifying that the ultrasonic equipment is performing as intended. It is carried out at the transducer level, the instrument level and the integrated system level. The frequency of calibration is based on practical field experience and is often mandated through consensus codes and standards.

Transducers are usually checked for their general condition and conformance to specified performance criteria, such as beam angle, depth resolution and absence of excessive reverberation noise, before beginning tests. The instrument's general condition is also checked. An ultrasonic test system's conformance to linearity performance limits is occasionally checked in a calibration laboratory, however, it is routinely adjusted to meet specific amplitude and distance calibration criteria before each field test. Finally, the transducer instrument positioning system is monitored for ongoing conformance to settings established at the beginning of each test. The frequency of system checks is usually mandated by test procedure specification, and is based on the risks of losing valid test data caused by the system falling out of calibration.

This chapter discusses how transducers, ultrasonic testing instruments and overall testing systems are calibrated during normal test practices.

Transducer Performance Checks

In general, the performance characteristics of transducers can be measured as they relate to fundamental generation and reception of ultrasonic energy or as part of checking their practical behavior related to testing effectiveness. The former is typically done in a laboratory equipped with special testing and positioning apparatuses. The latter is done by the technician before, during and after routine field tests.

Considered as a stand alone component, transducers can be characterized by their electrical and acoustic responses. Typical features include electrical amplitude and frequency responses, such as relative pulse echo sensitivity, center frequency, frequency bandwidth, time response, electrical impedance and sound field measurements. Typical approaches to transducer characterization can be found in documents such as the *Standard Guide for Evaluating Characteristics of Ultrasonic Search Units, ASTM E-1065.*

Transducers designed to generate angled shear waves are checked for depth resolution, precise beam location and refraction angle within a specified material. A standard widely used for this purpose is the International Institute of Welding calibration block (the *IIW block*).

Instrument Calibration

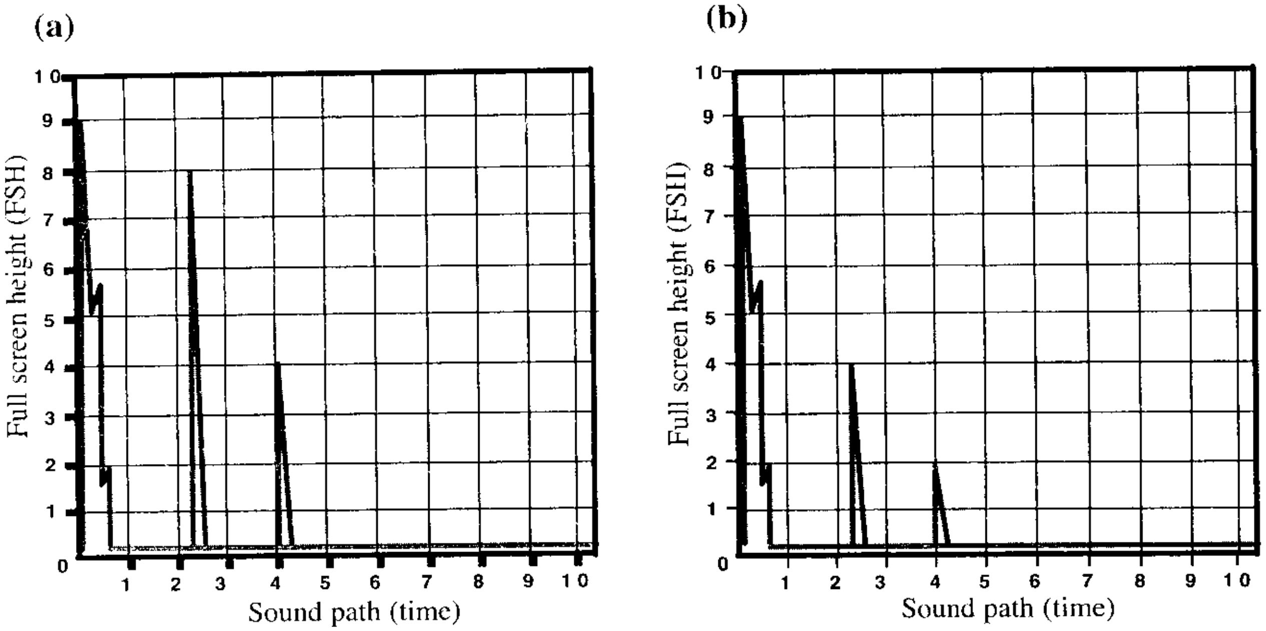
Amplitude Linearity

In analog instruments, measurements of signal strength (pulse height) and transit time (related to distance from sending transducer) are taken directly from the display screen. It is important in these instruments that the visual A-scan axes be directly proportional to incoming signal strength (vertical axis) and expended time (horizontal axis). Both axes must remain linear with respect to these two incoming signals throughout the operating range of the instrument. Since these variables are exclusively in the domain of the instrument's electronic circuitry, their calibration for linearity is often performed by technicians familiar with electronic circuitry during routine maintenance in the laboratory.

On-site checks of amplitude linearity (vertical axes) can be performed by observing how pairs of pulses, which differ in amplitude by some fixed amount, maintain their relative amplitude difference while changing the instrument's amplification. If the amplifier is linear, the ratio of the two pulses will remain the same as the gain of the instrument is changed over its operational range. An example of this is shown in Figure 7.1, where two signals are set to 80% and 40% of full screen height (FSH) in Figure 7.1a. The gain setting is then decreased by 6 dB, which should decrease the signal amplitudes by 50% resulting in the signals dropping to 40% and

20% FSH respectively, as shown in Figure 7.1b. If similar checks across the full vertical range (0 to 100% FSH) are within tolerance, the machine is considered to be linear in the vertical direction. Tolerances can be found in *ASTM E-317*, Figure 3.

Figure 7.1: Vertical linearity check: (a) two signals at 80% and 40% full screen height; and (b) same signals at –6 dB; 40% and 80% full screen height.

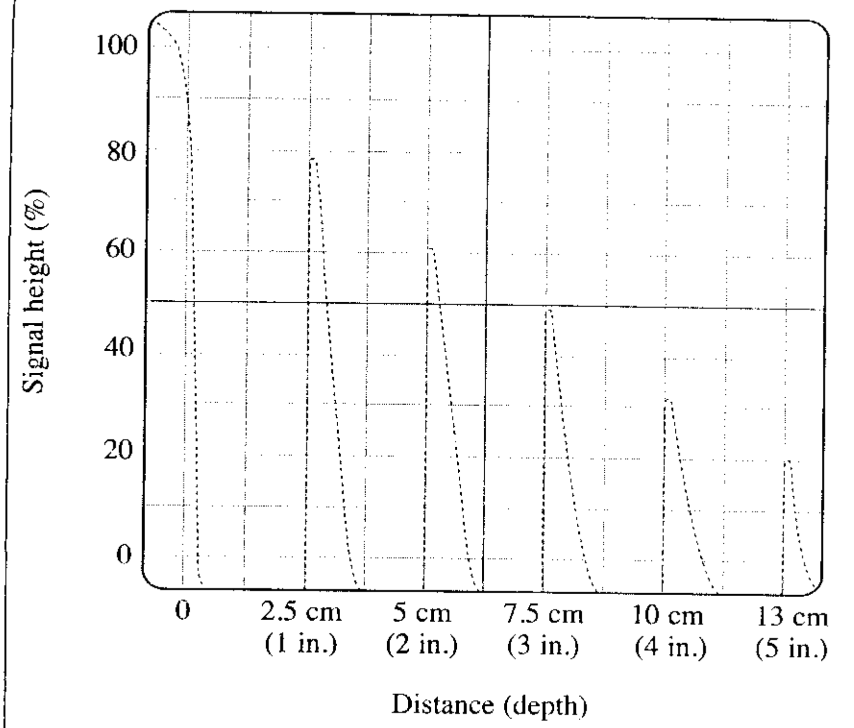


The basic calibration steps before a test include establishing the horizontal axis scale to correspond to the physical region of interest within the test object, and setting a basic sensitivity level (based on a standard reflector). When tests are made over extensive sound travel paths, assessments of effective sound attenuation are also taken and included in the calibration process. When test objects have contours and surface conditions different from those of the calibration block, these differences need to be assessed and compensations made when interpreting test results.

Straight Beam Calibration

For a simple longitudinal wave transducer (straight beam) test instrument, system level calibration typically uses any calibration block with a known thickness or depth to establish the range of thickness directly displayed on the screen. Using the multiple echoes as a relative gage, the screen width can be set to represent any distance significant to the test. Figure 7.2 shows a linear screen capable of displaying echoes at depths up to 13 cm (5 in.).

Figure 7.2: Screen calibrated for region of interest up to 13 cm (5 in.).

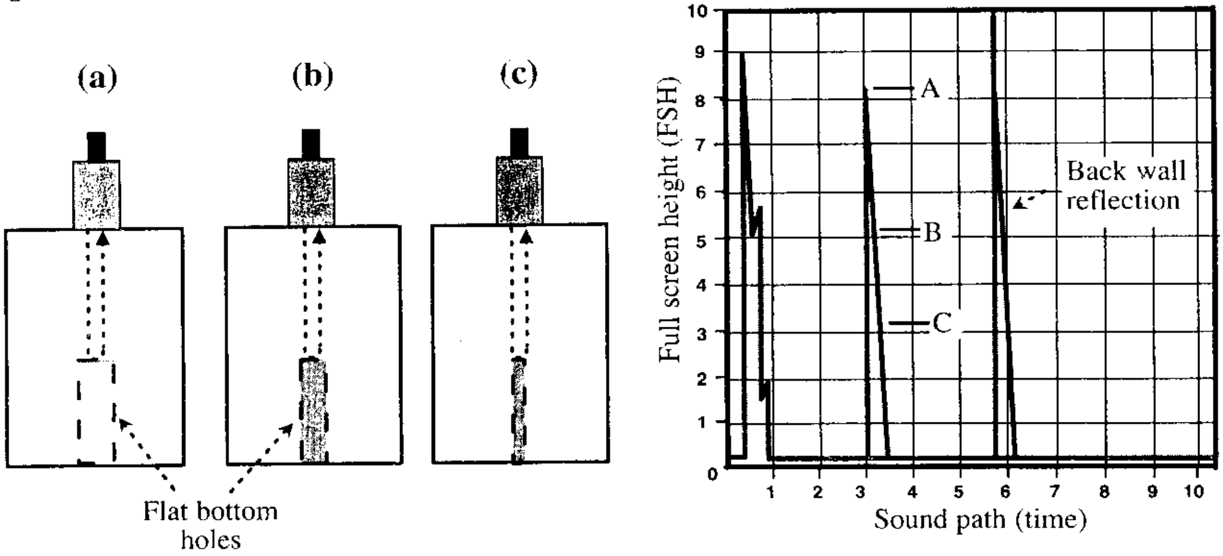


The sensitivity of the system is adjusted based on a standard reference reflector. Both side drilled holes (SDHs) and flat bottomed holes (FBHs) are used for this purpose. In special cases, custom reflectors placed in test object mockups are used to simulate the actual condition and testing environments of specific critical components.

Flat bottomed holes have historically been used as the basis for calibrating straight beam testing systems. Calibration blocks, called *area amplitude blocks*, are available in sets with a range of hole sizes. This allows setting basic sensitivities for relatively large reflectors (low sensitivity) through very small reflectors (requiring a highly sensitive detection system). Typical area amplitude blocks have FBH diameters that range from 1/64 to 8/64 in. (0.038 to 0.317 cm [0.015 to 0.125 in.]).

With area amplitude blocks, the sound path remains constant and the hole diameter changes. As a result of the reduced FBH surface area seen by the sound beam, the amplitude decreases as the FBH diameter decreases (amplitudes *A*, *B* and *C* on the screen representation in Figure 7.3). However, the location of the screen signal does not change horizontally since the sound path remains constant. A representation of this (not to scale) is shown in Figure 7.3.

Figure 7.3: Area amplitude blocks.



When the region to be tested involves relatively thick sections, the calibration process needs to determine the effective drop in sound energy with increasing distance. For straight beam applications, this is often done using distance amplitude blocks. These sets of blocks typically have FBHs of the same diameter, usually 3/64, 5/64 or 7/64 in. (0.13, 0.2 or 0.28 cm [0.05, 0.08 or 0.11 in.]). Each set of blocks come with sound path distances ranging from 1.6 to 14.6 cm (0.625 to 5.75 in.). They are used sequentially to establish the pattern of changes in reflector echo signal strength with increasing distance from the transducer. Figure 7.4 shows a general representation of three distance amplitude blocks and a typical screen presentation for each block.

Note that the decrease in screen amplitude is due to the increasing length of the sound path, not a change in FBH diameter. Unlike the area amplitude blocks, the signal location moves horizontally to the right as the sound path increases. The loss in amplitude is due to beam spread and attenuation that results in less of the sound beam seeing the FBH. If a curve were drawn from the peaks of each signal, that curve would be called a *distance amplitude correction* (*DAC*) *curve*. Figure 7.5 shows a typical pattern called a distance amplitude correction curve for a 13-block set.

The response curve derived from the distance amplitude holes becomes the basis for correcting readings taken during actual tests. For example, a discontinuity at a depth of 5 cm (2 in.), with the same effective reflecting area as another at a depth of 10 cm (4 in.), will appear on the screen to be four times bigger than the deeper reflector.

Figure 7.4: Distance amplitude blocks.

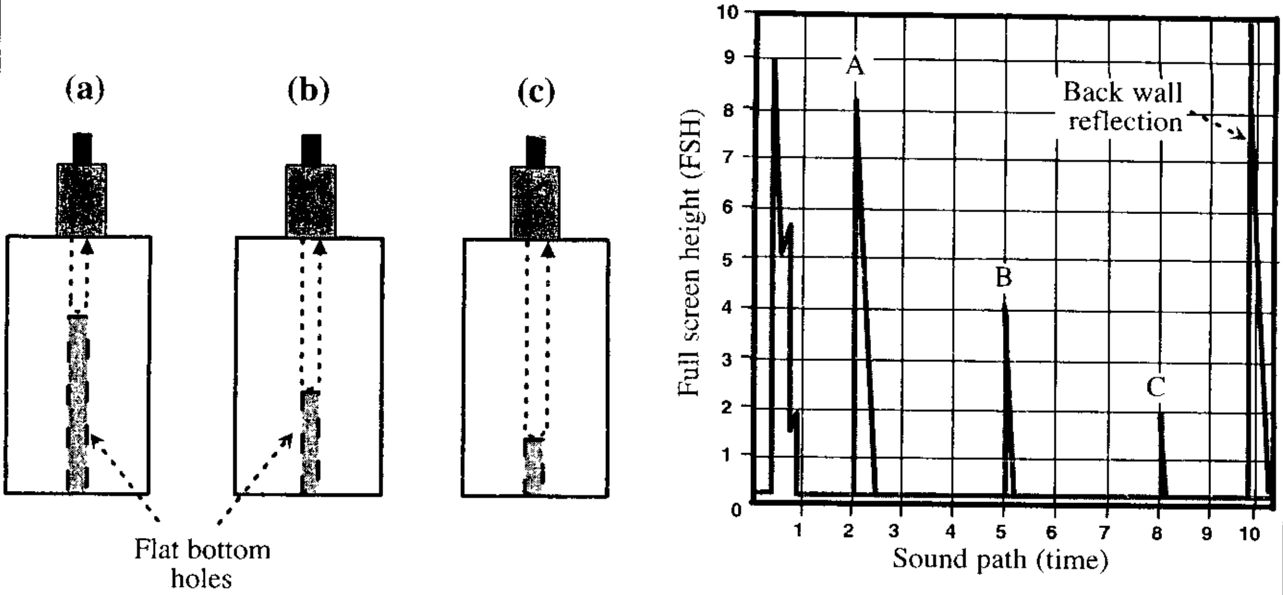
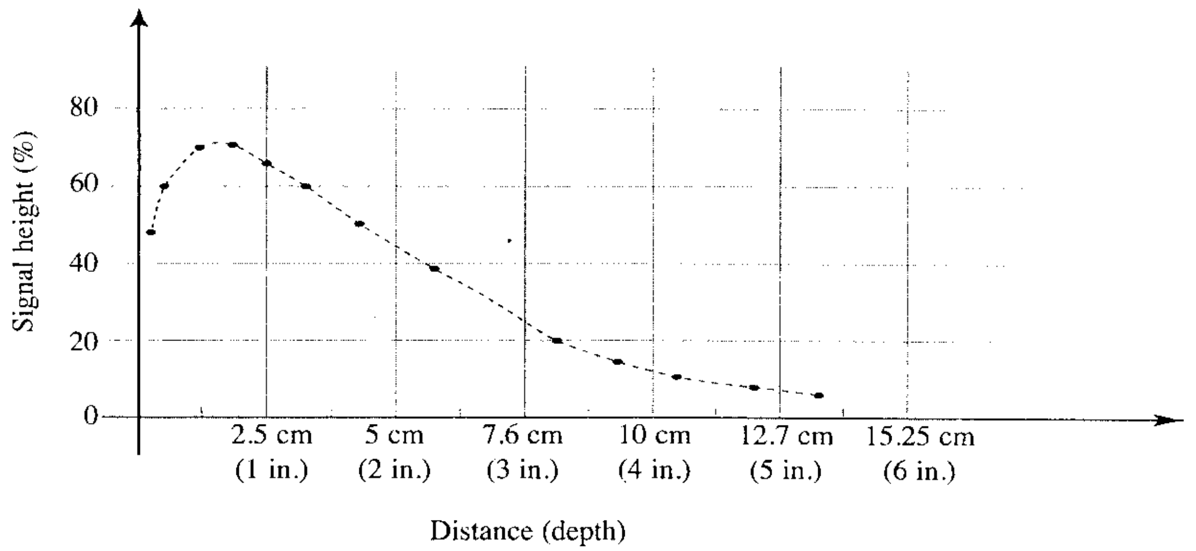


Figure 7.5: Typical distance amplitude correction curve using a set of distance amplitude blocks.



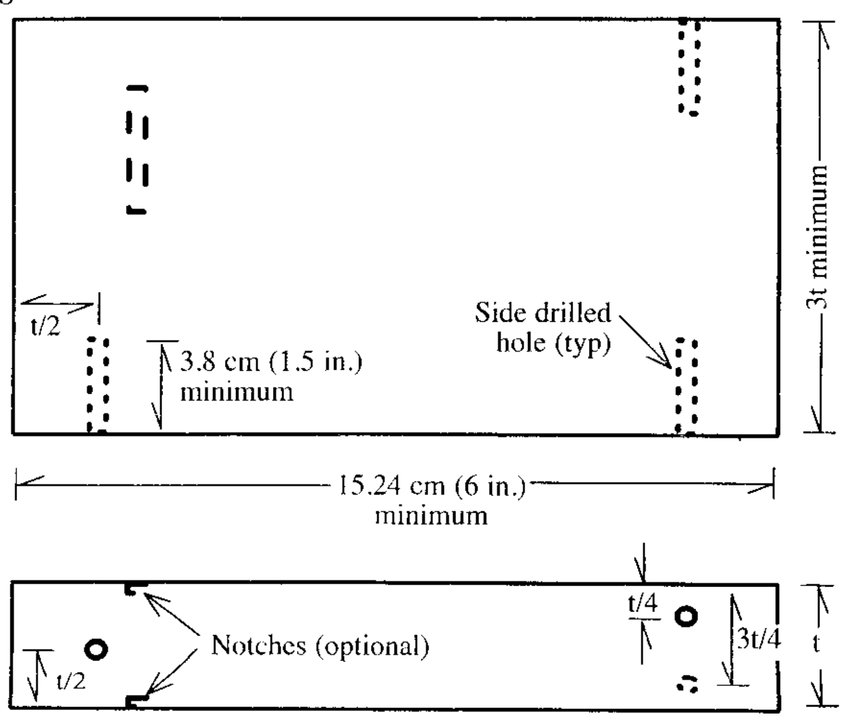
When using calibration blocks for ultrasonic testing, the required sensitivity is based on the size of the reference reflector, typically a flat bottomed hole or a side drilled hole. For tests with longer sound paths, the attenuation of the sound is estimated by creation of an appropriate distance amplitude correction curve. Additional corrections used to compensate for surface curvature, roughness or differences in the acoustic properties of the block and test object may also be required in special cases. Some of these cases are discussed in the context of certain standards covered in Chapter 11.

Side drilled holes have traditionally been used as the basis for calibrating angle beam test systems. Calibration blocks with side drilled holes have an added advantage: the amount of sound reflected from a side drilled hole remains the same regardless of the transducer angle. Several of the more common blocks used for angle beam calibration are the basic calibration block, the International Institute of Welding (IIW) block and the distance-sensitivity calibration (DSC) block.

Basic Calibration Block

The basic calibration block, shown in Figure 7.6, is rectangular with varying size and thickness, with thickness selection based on the thickness of the test object. The diameter of the side drilled holes vary based on the thickness; increasing in diameter as the block thickness increases. The holes are drilled and reamed to size so that the inner surface of the holes is as smooth as possible to provide a uniform reflector.

Figure 7.6: Basic calibration block.



The block must be long enough to allow a full skip distance for the transducer that is to be used, but may not be less than 15 cm (6 in.). As the thickness increases, the block will need to be longer to accommodate the longer skip distances.

The most common way to calibrate using the basic calibration block is to use the depth of each hole from the scanning surface to set the screen width. Figure 7.7 shows the sound paths for the first legs for 1/4t, 2/4 (1/2)t and 3/4t hole locations and the corresponding screen locations for each signal. Note that hole depths are designated in 1/4t increments.

Figure 7.7: First leg sound paths and screen locations.

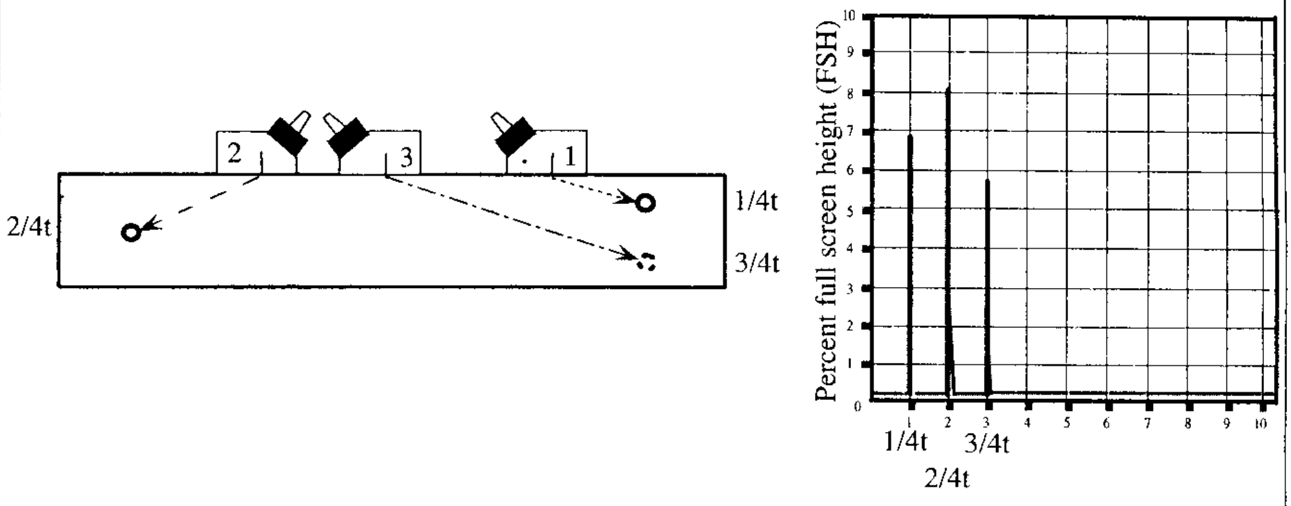
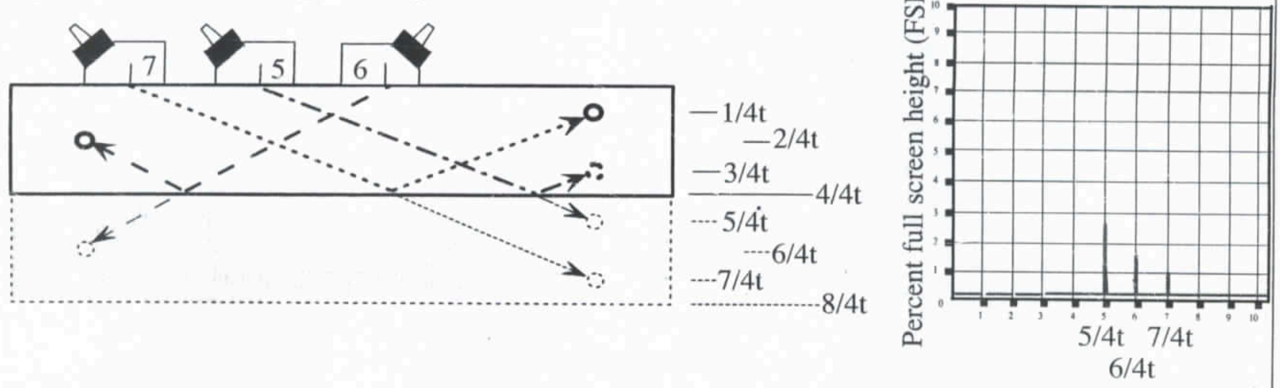


Figure 7.8 shows the same holes being interrogated in the second leg of the sound beam. Because the backwall of the block would be 1t, or 4/4t, and the sound hits the backwall at an angle, there is no reflection at 4/4t. However, when the 3/4t hole is seen in the second leg, the resulting sound path would be the same as if the hole was 1-1/4t, or 5/4t, below the scanning surface.

This can be seen graphically by imagining a mirror image of the block as shown by the shaded section in Figure 7.8 and imagining the sound path as continuing in a straight line. Similarly, when the 1/2t hole is seen in the second leg, the imaginary depth would be 6/4t and the 1/4t hole would show up at the 7/4t location. The 8/4t depth would be the scanning surface after a full skip distance, and as with the 4/4t depth, no reflection is seen. Because the sound paths are longer than those of the first leg, less sound is reflected and the resulting screen amplitudes are correspondingly lower, as shown.

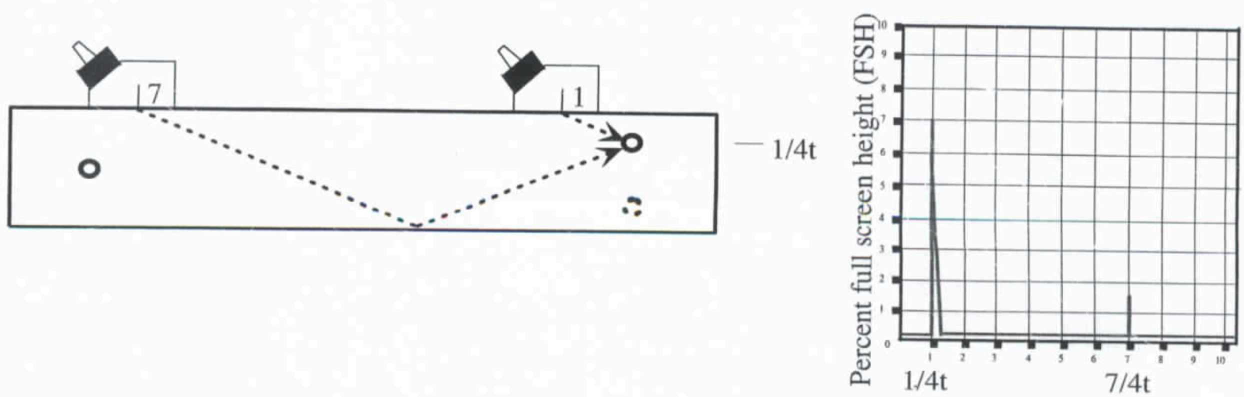
Figure 7.8: Second leg sound paths and screen locations.



Now the use of the depth designation in one-quarter thickness increments becomes apparent. Each one of the depths can be depicted on the screen at the corresponding graticule marker. That is, the 1/4t signal can be set at the first major graticule, the 2/4t signal at 2, etc. By doing this the screen, from zero to the eighth graticule, accurately represents twice the thickness of the calibration block being used.

To begin this type of calibration, the technician should maximize the return signal from the 1/4t hole, set the amplitude to 80% full screen height (FSH), then place it over the first graticule. The transducer is then slid backwards on the block until the 1/4t hole is seen in the second leg (7/4t location). This signal is then placed over the seventh graticule. The transducer is then moved forward again to hit the 1/4t hole in the first leg, and using the range and delay controls and repeating this process, the screen is adjusted until the 1/4t and 7/4t holes line up over the first and seventh graticules, as shown in Figure 7.9.

Figure 7.9: Initial calibration steps: basic block.



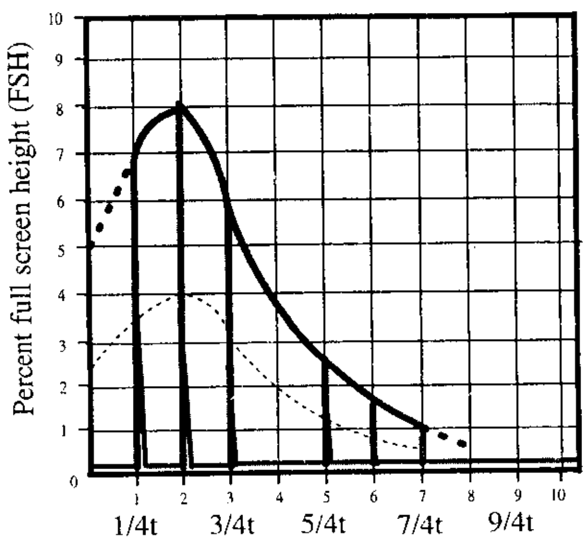
At this point, the signals from the other four locations (2/4t, 3/4t, 5/4t and 6/4t) should line up over the second, third, fifth and sixth major graticules, respectively. If they do not, the range and delay controls should be adjusted until all signals line up where they belong. As noted previously, there will be no screen signals at the 4/4t and 8/4t locations.

In some instances, the signal amplitude from the 2/4t hole may be higher than the amplitude of the signal from the 1/4t hole. If this occurs, the gain (decibel level) should be set so that the signal from the 2/4t hole is set at 80% FSH (or whatever screen height is specified in the governing code or specification) and the signal locations from all six hole positions should be rechecked. This gain setting should be recorded, as it becomes the reference level for the inspection process.

Without changing the reference level gain setting, the peak of each maximized signal can be marked on the screen using a china marker, and those points can be connected to create a DAC curve similar to that shown in Figure 7.5. This curve, shown in Figure 7.10, then becomes the rejection level for signals found during the test. (Note: Some codes require that a line be marked at 50% DAC height, which is shown by the light dashed line in Figure 7.10). Since there are no signals from the scanning surface at the zero (0) and 8/8t positions, the DAC curve should be extrapolated back to zero and out to the 8/8 screen position.

When inspecting using a DAC curve, scanning is performed at a gain level above the reference level (as described in the governing code or specification) and if an indication is found, the gain is reset to the reference level. If the signal amplitude at reference exceeds DAC, the indication is rejectable.

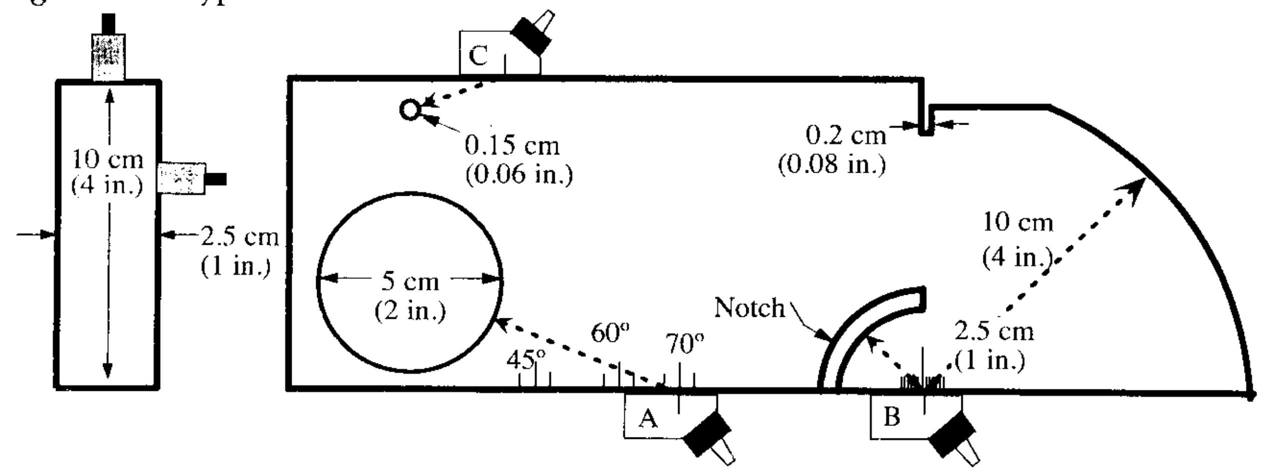
Figure 7.10: Completed distance amplitude correction (DAC) curve.



International Institute of Welding (IIW) Block

Another commonly used calibration block is the International Institute of Welding (IIW) block. This block comes in several different types and in multiple materials. For this discussion, the Type 1 IIW block, shown in Figure 7.11, will be used.

Figure 7.11: Type 1 IIW block.



This block provides the technician with many options. For straight beam calibration the block can be scanned from the side (2.5 cm [1 in.] thickness) to set up screen widths in 2.5 cm (1 in.) multiples, or from the edge through the 4 in. width for wider screen widths, and the 0.2 cm (0.08 in.) notch can be viewed from the opposite side of the block to check transducer resolution.

For angle beam work, the angle of the transducer wedge can be placed in position *A* on the IIW block and the return signal from the 5 cm (2 in.) diameter hole maximized. With the signal maximized, the technician can see where the exit point of the wedge is located. In the figure, the transducer exit point is shown on the 70° line, so this transducer wedge angle is within acceptable tolerance. Many codes and specifications require that the actual wedge angle be within +/–2° of the nominal angle (45°, 60° or 70°). If the actual wedge angle is outside of the specified range, the transducer may not be used for inspection work until it is brought back into the acceptable range.

Note: Most wedges can be corrected by sanding the scanning face on a flat surface. For wedges that have a low angle (<68°), the rear of the wedge should be sanded down; for wedges with high angles (>72°), the nose should be sanded down.

Prior to beginning a calibration using the IIW block, the technician must determine what screen width will be required to perform the test. Unlike DAC curve calibrations on a basic block, when the IIW block is used the screen width is not determined by the depth of reference holes. Screen width selection in an IIW