OPINION

Origin of AWS D1.1/D1.5 Indication Rating UT Technique

by Gary S. Martin

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As an ultrasonic testing (UT) inspector, have you ever had an assignment that required you to use the UT technique specified in code language sections of the American Welding Society (AWS) D1.1 (*Structural Welding Code – Steel*) or D1.5 (*Bridge Welding Code*)? What were your opinions? Did you think it was outdated? Did you wonder why it didn't call for DAC (distance amplitude correction) or DGS (distance/gain/size) curves? Or, did you think this technique was pure genius, and wonder why everyone doesn't use it? Such is the way of life—there are many gray areas and differing opinions in all aspects of inspection and testing of materials.

Regardless of your opinion, you might be wondering about the "who," "how," and "when" behind the development of this technique. Well, read on and I will divulge some answers to these mysterious questions.

This will not be an instructional guide on how to UT inspect per the AWS D1.1 or D1.5 codes, as there are many well-written articles already in circulation on this topic. Instead, I will provide a brief overview of the technique along with some history about the development of the code.

Overview of Technique

Unless you have a copy of the AWS D1.1 code or are very familiar with the Part F content (Ultrasonic Testing of Groove Welds), or you have significant experience using this technique, you might not understand what I am talking about in the rest of the article. Therefore, in the following section, a brief overview of the technique is provided.

Rather than using a reference or block with multiple artificial defects to standardize a reject curve, the AWS D1.1/1.5 indication rating technique relies on the signal from a single standard reflector and an equation to characterize the UT response indication as acceptable or not (AWS 2015a, 2015b, 2020). (Note that I used the word *standardize*, as I was recently informed that what we called *calibration* for testing is an improper term according to ASTM E1316. When you are setting up a UT machine to perform a particular inspection technique, you are standardizing, not calibrating.)

The first basic step in applying the AWS Part F technique (note that there are other allowed techniques in the code, but they must be approved by the engineer) is to standardize the response of the 0.060 in. (0.15 cm) side-drilled hole in an International Institute of Welding (IIW) type reference block to the desired screen height (the operator's choice between 40% and 60% full screen height [%FSH]). The operator records that decibel (dB) gain as the reference level, known as variable *b*. Next, the operator scans the selected weldment as instructed in the code. When an indication appears above the background noise, the operator adjusts the gain up or down to reach the same selected %FSH that was determined during standardization. This is known as variable *a*. The operator then subtracts the reference gain value (*b*) and the sound attenuation value (*c*) from *a*. The sound attenuation is determined by taking the sound path, subtracting 1 in., and then doubling the remainder. The final remainder is the indication rating, *d* (Equation 1).

Some of you may point out that this formula doesn't work if you are using an attenuator instrument, and you would be correct. However, the code has a proper formula for this that

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reverses the reference and indication gain values (Equation 2). (That being said, when was the last time someone used an attenuator-controlled UT instrument?) Following are the formulas as specified in the code:

(Eq. 1) Instruments with gain (in dB): $a - b - c = d$

(Eq. 2) Instruments with attenuation (in dB): $b - a - c = d$

Once d is determined, confer with the appropriate acceptance criteria from D1.1 table 8.2 or 8.3 (in the 2020 edition) or table 6.2 or 6.3 (in the 2015 edition), depending on structural loading type, and compare the value according to the appropriate weld size and probe angle column. There are four discontinuity classes that depend on the d value and determine acceptance based on the length of the indication. Class A is rejected regardless of the length of indication, class D is acceptable regardless of length, and B and C are limited to 0.75 and 2 in. (1.9 and 5.1 cm) maximum lengths, respectively. There are other details, such as spacing, to consider as well. Today's modern digital UT machines have software options that compute the d value continuously, assuming the operator has input the appropriate reference gain and weld thickness.

What is described here are only the most basic tenants of this technique. There are many other requirements related to probe size, frequency, angle, and scanning pattern.

History of the AWS Code

As a UT practitioner seeing this for the first time, you might think that using DAC or DGS techniques are far simpler to standardize and use. I would not argue one way or the other on that point, but you have to understand two things about code-writing bodies. They tend to be slow to adopt new technology and are equally slow to shelve techniques that may seem to no longer be useful.

Consider the state-of-the-art of UT inspection in the early to mid-1960s, when it was first proposed for the AWS structural steel code. There were no digital units, no liquid crystal (LCD) or color displays, and no software capability for electronic DAC or DGS curve generation—only cathode-ray tube oscilloscope displays, mylar grid overlays, and grease pencils. While I don't have hard evidence that the current state-of-the-art in equipment and techniques was the main driver in directing the task group that developed the AWS technique, I'm certain it had some influence. I suspect that the repeatability of grease pencil marks on mylar screens might have concerned the task group members somewhat. What I can tell you is that this technique is still in use, and structures that were inspected by operators properly using this technique have met their design life and service requirements.

In 1928, Soviet scientist Sergei Y. Sokolov demonstrated how to use ultrasonics to detect defects in metals. In 1969, the AWS bridge and building codes first introduced language for conducting UT examination of weld joints (Shenefelt 1971). As you can see, it took about four decades to go from concept to code language. You might wonder why it took so long to adopt this technology into the AWS code. There are a lot of factors to consider here:

- Any new and emerging technology has to be stable and well established for general use, and not a hacked-together lab-only system.
- There has to be sufficient equipment with commercial availability, material/technical support, and infrastructure.
- There must be sufficient parts, service, and standardization availability for the equipment required to carry out the inspection method.
- There has to be enough competition and maturity in the market for the equipment to be affordable and widely available.
- There have to be enough trained, skilled, and experienced operators to make the application available, deployable, and affordable.
- Code-writing bodies rely on volunteers who might meet only a few times a year and work on their own time to propose code language.
- The process of approving code language can take many years of presentation, comment review, rewriting, discussion, voting, and publishing.

One needs to keep in mind that this code language was created before email, personal computers, or conference calling was widely available. It was done via face-to-face meetings, one-on-one phone calls, faxes, and US mail.

UT procedures were first introduced in 1969 as Appendix C to both AWS D1.0, *Welding in Building Construction*, and D2.0, *Welded Highway and Railway Bridges* (now D1.1 and D1.5, respectively). A task group was assigned to develop what became the new UT code. It consisted of George A. Shenefelt of American Bridge (Ambridge), Dexter A. Olssen of Bethlehem Steel, and Bill Carnes of the Pittsburgh Testing Laboratory. Shenefelt spent 40 years in the pattern shop at Ambridge and was obsessed with precision. Angles and distances were his daily work. He believed completely in the UT research results published by Joseph and Herbert Krautkramer in the early 1960s, specifically that the size of a reflector could be measured by the amplitude of its response. He developed the code believing that the amplitude of sound reflected from an indication was an accurate measure of its structural severity.

Once the new code language was released, there was some amount of government and university interest and research conducted. While subsequent investigations and research pointed out a few flaws in the assumptions behind the technique, overall it was supported as an inspection technique that was effective, reproducible, and cost-effective. It was capable of determining that there were no defects that were likely to cause failure under most conditions (Shenefelt 1971). There have been almost no substantial changes made to the code language since its introduction in 1969, and it is still widely used at the time of the publication of this article.

When the task group, headed by Shenefelt, started their work, they were instructed that the code should be of a straightforward nature, so that the same results could be attained by all operators. D1 committee management also insisted that the ultrasonic code should, as closely as possible, parallel the radiographic code.

Since the radiographic code uses a penetrometer thickness of 2% of the weld thickness in the evaluation of radiograph quality, and the 2% is usually considered to be the maximum acceptance sensitivity, the same 2% of weld thickness sensitivity was considered by the task group when establishing the ultrasonic code.

Basis of the Technique

The exact application of the probe, the probe frequency, size, and angle are all specified in the code in order to attain consistent and reproducible results. Use of other angles, sizes, frequencies, or weld faces may result in a more or less critical examination than that established by the code. The basis for this technique is illustrated in Figure 1.

Assuming that a weld defect might be oriented in the most serious direction, which would be perpendicular to the lines of stress (most detrimental to the weld structure), the decibel ratings are based on the application of position A as shown in Figure 1. Since this position is not possible for testing welds, a choice of positions B, C, or D is used, with 6 dB of sensitivity added for the unfavorable 20° angle between positions A and B; 9 dB between positions A and C; and 11 dB between A and D. These factors are built into the acceptance levels of the code.

The factor of sound attenuation is where some criticism has been historically directed at this technique. While it is not technically accurate, as we know today, it still results in meaningful and reliable results. Here are the assumptions made when it was developed:

- sound attenuation is linear
- no attenuation in the first inch (2.5 cm)
- 2% sensitivity, so larger defects are allowed in thicker sections
- 3 dB loss between 70° and 60°; 2 dB loss between 60° and 45°

The operator has to take into consideration that there are expressed limitations for the application of this technique as well. They are as follows:

- It is only applicable to UT of groove welds and heat-affected zones (HAZs) with thicknesses of between 0.31 and 8 in. (8 and 200 mm), inclusive.
- It is prohibited for testing tube-to-tube T-, Y-, or K-connections.
- The operator must conduct a longitudinal scan of the material under the shear wave scanning area to determine if there are any planar reflectors that would interfere or confound the subsequent shear wave testing.

If the number or size of planar reflectors in the scanning area is significant, then other inspection methods or techniques may need to be used. A Level III should be consulted when this occurs.

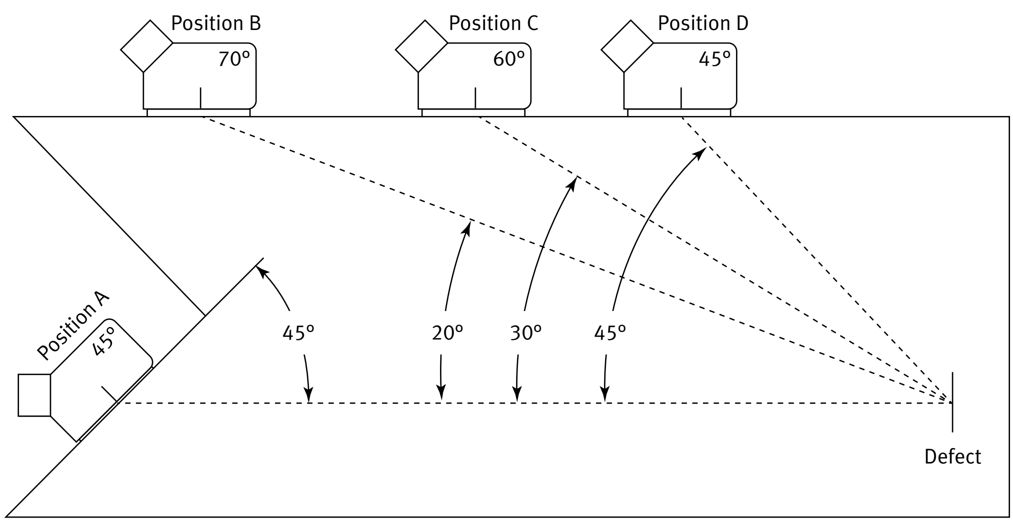

Figure 1. Basis of the AWS indication rating technique.

Table 1. Indication rating analysis using data from AWS D1.1-2020, tables 8.2 and 8.3

	0.31–0.75 in.			0.75–1.5 in.			1.5–2.5 in.									2.5– 4 in.									4–8 in.								
	70°			70°			70°			60°			45°			70°			60°			45°			70°			60°			45°		
Discontinuity severity class	.2	.3	Delta	.2	.3	Delta	.2	.3	Delta	.2	.3	Delta	.2	.3	Delta	.2	.3	Delta	.2	.3	Delta	.2	.3	Delta	.2	.3	Delta	.2	.3	Delta	.2	.3	Delta
A	5	10	5	2	8	6	−2	4	6	1	7	6	3	9	6	−5	1	6	−2	4	6	0	6	6	−7	−2	5	−4	1	5	−1	3	4
B	6	11	5	3	9	6	−1	5	6	2	8	6	4	10	6	−4	2	6	−1	5	6	1	7	6	−6	−1	5	−3	2	5	0	4	4
C	7	12	5	4	10	6	1	7	6	4	10	6	6	12	6	−2	4	6	1	7	6	3	9	6	−4	1	5	−1	4	5	2	6	4
D	8	13	5	5	11	6	3	9	6	6	12	6	8	14	6	3	6	3	3	9	6	5	11	6	3	3	0	3	6	3	4	8	4
Delta between angles	A										70 vs 60	3		60 vs 45	2					70 vs 60	3		60 vs 45	2					70 vs 60	3		60 vs 45	3
Delta between angles	B										70 vs 60	3		60 vs 45	2					70 vs 60	3		60 vs 45	2					70 vs 60	3		60 vs 45	3
Delta between angles	C										70 vs 60	3		60 vs 45	2					70 vs 60	3		60 vs 45	2					70 vs 60	3		60 vs 45	3
Delta between angles	D										70 vs 60	3		60 vs 45	2					70 vs 60	0		60 vs 45	2					70 vs 60	0		60 vs 45	1
1 in. = 2.54 cm																																	

Conclusion

An updated version of the AWS D1.1 code was published in 2020 (AWS 2020). In my opinion, there remain some flaws in the current code language related to this technique. These include:

- The testing angle table (table 8.7) has no solution for T or corner joints over 7 in. (17.78 cm) in material thickness.
- Modern digital UT instruments can measure sound path and decibel values to the third and second decimal places, respectively, but the discontinuity length is subject to operator interpretation and the decibel values can be significantly altered depending on the surface finish, couplant, and probe application pressure.
- The testing angle table is based on material thickness and the acceptance criteria tables are based on weld thickness, and the thickness ranges do not align consistently.

The indication rating delta between transducer angles is not consistent with Figure 1 determinations, as shown in Table 1. The values in the blue shading are consistent; the other shades are not.

In conclusion, there were some flaws in the assumptions that led to the AWS technique that have resulted in some discrepancies. However, the AWS technique is still widely used and has been historically shown to be an effective, reproducible, and cost-effective technique for finding defects that might lead to structural failure. ●

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Disclaimer: The author is currently a member of the AWS D1 Code Committee. The opinions stated here are his own and not stated on behalf of AWS or the D1 Committee.

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