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Demonstration of Ultrasonic Guided Wave Examination Capability for FAC Damage and Circumferential Cracking

1019285

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Technical Update, May 2009

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PRODUCT DESCRIPTION

The detection and monitoring of flow-accelerated corrosion (FAC) is a significant cost to the power generation industry. Identifying technologies that can improve results and reduce the cost of FAC monitoring will be beneficial to the industry. The objective of this project was to determine the capability of ultrasonic guided waves to identify locations of FAC damage. Additionally, this project looked at the capability of ultrasonic guided waves in identifying circumferential-radial planar flaws such as cracks associated with girth welds. These types of flaws can be associated with a number of degradation mechanisms, in particular, creep cracking that occurs in or near the heat-affected zone of girth welds.

Results and Findings

Ultrasonic guided waves can detect FAC-related damage as well as circumferential radial cracks. Proper application of guided waves can reduce the cost of monitoring programs by reducing insulation removal costs and the possible number of monitoring locations. It has been shown that ultrasonic guided waves can detect circumferential radial cracks and could be used as a screening tool for identifying advanced stages of such damage.

Challenges and Objectives

This report may be useful for people who are considering the use of ultrasonic guided waves for piping assessment and who want a more in-depth understanding of this technology. FAC and high-energy piping engineers may find that the results are insightful and provide them with another tool to use in their programs.

Applications, Value, and Use

The project identified four basic damage morphologies related to FAC and circumferential cracking. Additional work may be needed to further quantify detectable limits and other specific flaw morphologies. This project identified the need for specific FAC-related training for examiners to maximize the detectability of the technology.

EPRI Perspective

The nondestructive evaluation (NDE) activities performed in support of this report were conducted by engineers who are certified ultrasonic guided wave examiners and have over 30 years experience in assessing power plant components. NDE performed by less experienced individuals or by individuals who have not received appropriate training in ultrasonic guided wave examinations may not be as successful as the results shown in this report.

Approach

The goals of this report were to evaluate the capability of ultrasonic guided waves for the detection of FAC and also to evaluate ultrasonic guided wave examination for the detection of circumferential cracking adjacent to circumferential pipe welds. The researchers demonstrated that this technology is capable of detecting and discriminating FAC damage and circumferential cracking from girth weld geometries. However, the smaller the changes in damage, the more difficult it is to discern flaws. In each case, flaws associated with girth welds increase the difficulty of detection.

Keywords
Guided wave ultrasonic examination
Flow-accelerated corrosion
Nondestructive evaluation
Type IV cracking
G-Scan

ACKNOWLEDGMENTS

Structural Integrity Associates thanks EPRI for giving us this opportunity to conduct this demonstration project. It is Structural Integrity's hope that member companies find this work directly applicable to determining the viability of applying guided wave ultrasonic examination to their assessment projects.

CONTENTS

1

BACKGROUND

Project Overview

The power generation industry spends significant funds on the detection and monitoring of flow accelerated corrosion (FAC). This damage mechanism is often associated with wall thinning at or near fittings and welds of a piping system and can result in the reduction of the pressure carrying capacity of the piping. One of the fundamental challenges in monitoring for FAC is identifying locations that are experiencing FAC. The objective of this project is to determine the capability of Guided Wave Ultrasonic Testing (GWUT) in identifying locations of FAC damage.

Additionally, this project looks at the capability of GWUT in identifying circumferential-radial planar flaws such as cracks associated with girth welds. These types of flaws can be associated with a number of degradation mechanisms, in particular, creep cracking occurring in or near the heat affected zone of girth welds.

Guided Wave Ultrasonic Testing Overview

GWUT technology was initially developed to detect wall thinning in the oil and gas industry and started to be used commercially in the 1990’s. Since that time, the equipment and supporting software have been updated to improve analysis capabilities and have been expanded to be used in nuclear, fossil, and hydro generating facilities. The targeted application for GWUT is a screening tool to detect changes in cross-sectional areas of piping. This includes piping under insulation, piping that is difficult to access, underground piping, or long lengths of piping/tubing such as in boilers. A technical explanation of the technology is provided in Section 2 of this report.

Technical Approach

Damage morphologies typically associated with FAC and circumferential cracking were replicated in a test loop at a laboratory. GWUT was performed on this test loop before and after the introduction of the simulated damage. The GWUT response from the simulated damage was compared to the baseline response. Amplitude and pattern measurements were made and identified. Observations and conclusions for each of the damage morphologies were drawn regarding detectability and examination protocol. Descriptions of the morphologies and the test results are discussed in Section 3 of this report.

2

GUIDED WAVE ULTRASONIC TESTING

To aid in the understanding of the GWUT examination and the results of this project, an overview of GWUT is provided in the following sections. Although the description of the technology is somewhat detailed, it nevertheless is a summary and not a complete explanation of the technology.

Applications

GWUT operates much differently than most conventional ultrasonic examination techniques. Instead of evaluating the material directly below or near the transducers, ultrasonic guided waves travel down the length of the pipe and are reflected off of features that cause a change in cross-sectional area or torsional stiffness of the pipe. This results in screening lengths of pipe typically ranging from 40 to 300 feet (12 to 90 meters) from a single examination location. Figure 2-1 shows a comparison of the areas screened from a typical ultrasonic thickness measurement and a guided wave screening.

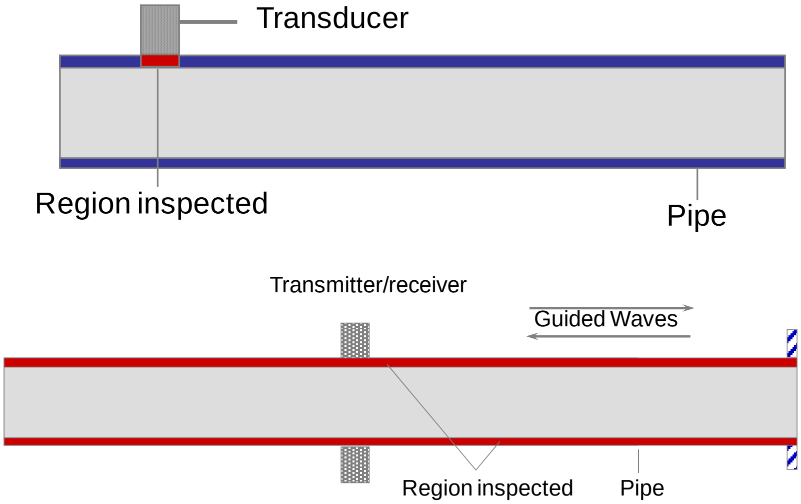

Figure 2-1
Comparison of Examination Area from Conventional Ultrasonic Thickness Measurements and GWUT

Since guided waves are reflected from changes in cross-sectional areas of pipes, degradation or features on either the interior or the exterior of the pipe can be detected. In power generating facilities, GWUT has been used for:

- Corrosion Under Insulation: To determine external corrosion from beneath the insulation.
- Water System Degradation: Service water, fire protection, circulating water systems for the evaluation of internal corrosion.
- Buried Piping Degradation: Wide range of piping systems that may suffer from soil side or internal corrosion
- Boiler Tube Wastage: Fireside corrosion, internal pitting, fly ash erosion
- Locating Girth Welds: For main steam and hot reheat piping to facilitate further high temperature degradation assessments.
- Flow Accelerated Corrosion: General screening and identification of areas with varying degrees of wall loss.

New potential uses for GWUT are frequently identified. Often, because of the unique capabilities and limitations of the technology, demonstration projects similar to this project are conducted to better understand the uses and limitations of GWUT.

GWUT Equipment

A GWUT system is composed principally of three components: transducer collar, pulsar, and laptop computer. The functionality of each of these components is further described in the sections below. The equipment used in this project was developed and manufactured by Guided Ultrasonics Limited. Other companies manufacture the equipment with different designs and capabilities. However, the purpose of the principle components remains similar to the ones described here.

Transducer Collar

Transducer collars are used to introduce the guided waves into the pipe and to detect reflected waves from features and wall loss. Figure 2-2 shows the two basic types of transducer collars; rigid or hard collar used on smaller diameter pipes up to 10 inches (250 mm) in diameter and inflatable collars used on larger diameter pipes typically up to 36 inches (900 mm) in diameter[1].

Typically, the collars have two rows of piezoelectric transducers. The collars are designed to be dry-coupled to the pipe and usually only take minutes to install. Minimal surface preparation is typically required to remove loose scale[2]. The collars can be installed on pipes up to 300°F (150°C). Due to heat restraints for the piezoelectric transducers and the plastic transducer modules the transducer collars cannot be used on hotter pipes.

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[1] Pipes larger than 36 inches (900 mm) can be examined by connecting two collars nearly in size together.

[2] Paint does not usually need to be removed. Coatings for underground service such as coal tar need to be removed at the collar location.

Pulser

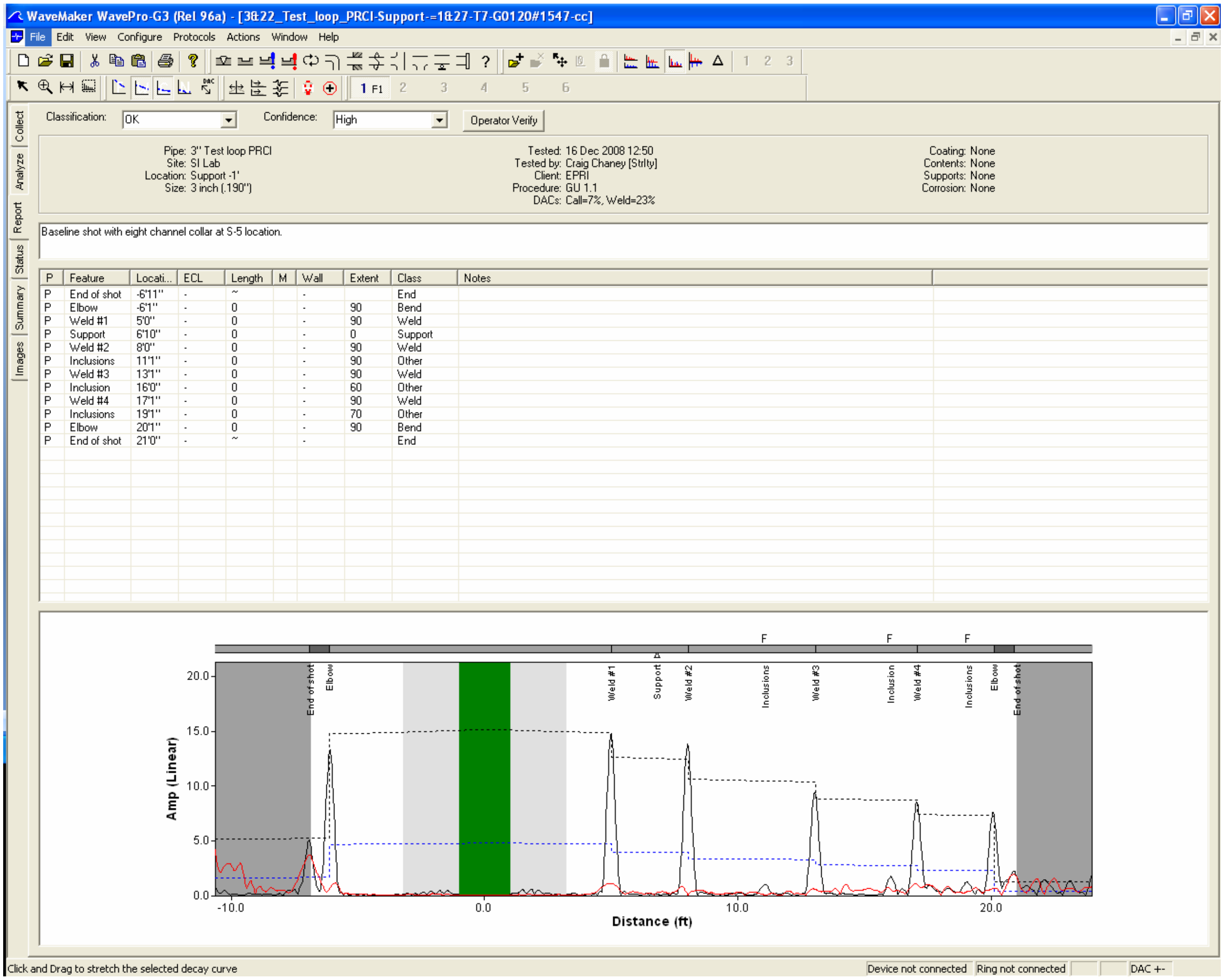
Figure 2-3 shows the GUL G3 pulser. This unit is the third generation of the GUL pulsars and includes a significant improvement in frequency interpolation. The pulser unit provides signal and energy to the transducer collar and does much of the signal processing. During each examination, it performs a series of diagnostic checks on the pulser, the transducer collar, and the cables. The unit is battery operated and portable.

Figure 2-2
Guided Ultrasonics Ltd. Transducer Collars. Hard Collar is Black, Inflatable Collar is Blue.

Figure 2-3
GUL G3 Guided Wave Ultrasonic Pulser

Laptop and Analysis Software

Typically, a ruggedized laptop computer is used for in-field GWUT data collection and analysis. The laptop is connected to the pulser via an umbilical cord. The examination is controlled, saved, and analyzed on the laptop. Specialized software is used to analyze and report the results. Figure 2-4 shows a typical screen save of one of the examinations conducted for this project.



Classification: OK
Confidence: High

Pipe: 3" Test loop PRCI
Site: SI Lab
Location: Support -1'
Size: 3 inch (.190")

Tested: 16 Dec 2008 12:50
Tested by: Craig Chaney [Strlty]
Client: EPRI
Procedure: GU 1.1
DACs: Call=7%, Weld=23%

Coating: None
Contents: None
Supports: None
Corrosion: None

Baseline shot with eight channel collar at S-5 location.

P	Feature	Locati...	ECL	Length	M	Wall	Extent	Class	Notes
P	End of shot	-6'11"	-	~		-		End	
P	Elbow	-6'1"	-	0		-	90	Bend	
P	Weld #1	5'0"	-	0		-	90	Weld	
P	Support	6'10"	-	0		-	0	Support	
P	Weld #2	8'0"	-	0		-	90	Weld	
P	Inclusions	11'1"	-	0		-	90	Other	
P	Weld #3	13'1"	-	0		-	90	Weld	
P	Inclusion	16'0"	-	0		-	60	Other	
P	Weld #4	17'1"	-	0		-	90	Weld	
P	Inclusions	19'1"	-	0		-	70	Other	
P	Elbow	20'1"	-	0		-	90	Bend	
P	End of shot	21'0"	-	~		-		End	

Figure 2-4
Screen Save of WavePro™ Software for Baseline Examination

Ultrasonic Guided Waves

Torsional Guided Waves

Guided waves are formed by introducing ultrasonic waves into the pipe that have a longer wave length than the thickness of the pipe. Historically, longitudinal (compression) and torsional waves were used for GWUT. However, torsional waves are now predominantly used for examination and were used in this project. Figure 2-5 contains a drawing depicting the torsional wave (a twisting motion of the wave in the pipe, symmetrically around the pipe axis).

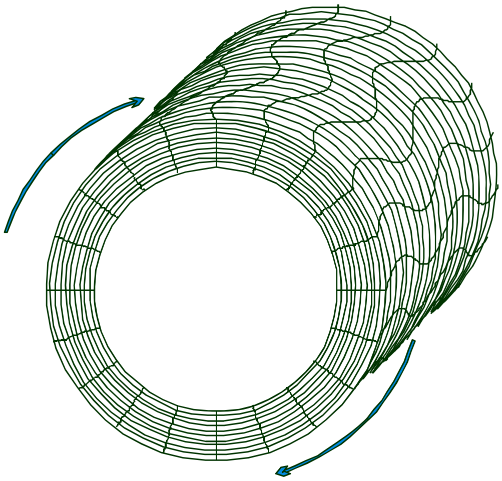


Figure 2-5
Depiction of a Torsional Guided Wave in a Pipe

One of the wave modes that are reflected from pipe features is the torsional wave. The amplitude of this reflection is usually proportional to the cross-sectional area change of the feature in the pipe. This signal is represented by the black lines in the test results as can be seen in Figure 2-4.

Reflections from a Symmetric Feature

When a guided wave comes into contact with a change in cross-sectional area, there is a representing change in stiffness of the pipe. This change in stiffness causes acoustic impedance and results in a portion of the energy being reflected back to the transducer collar as shown in Figure 2-6. This reflection results in less energy propagating down the pipe. This is one mechanism of signal attenuation that governs the length of pipe that can be screened during an examination. The change in cross-sectional area can be either an increase or a decrease to cause a reflection. The reflection almost always results in a torsional or symmetric wave to be reflected back to the collar.

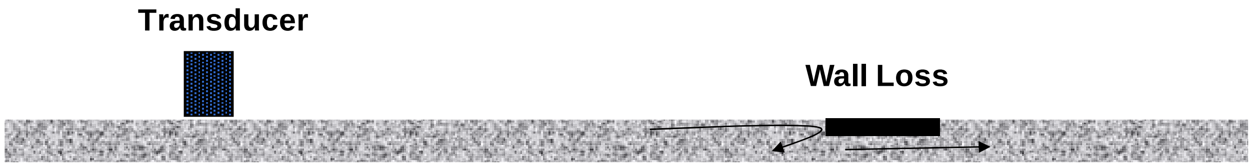


Figure 2-6
The Nature of a Guided Wave Reflection from a Change in Cross-Sectional Area

Figure 2-7 shows the baseline trace of the test loop prior to the introductions of flaws. The green band is the location of the transducer collar and depicts the dead zone where the GWUT cannot evaluate the integrity of the pipe. The horizontal axis is the distance along the pipe and shows the negative and positive direction in relationship to the transducer collar. The figure shows the symmetric responses from the welds in the test loop (black peaks). The dotted lines represent the Distance Amplitude Correction (DAC) curves. Note the step decreases of the weld DAC at each weld depicting the decrease in energy from the reflection of each weld.

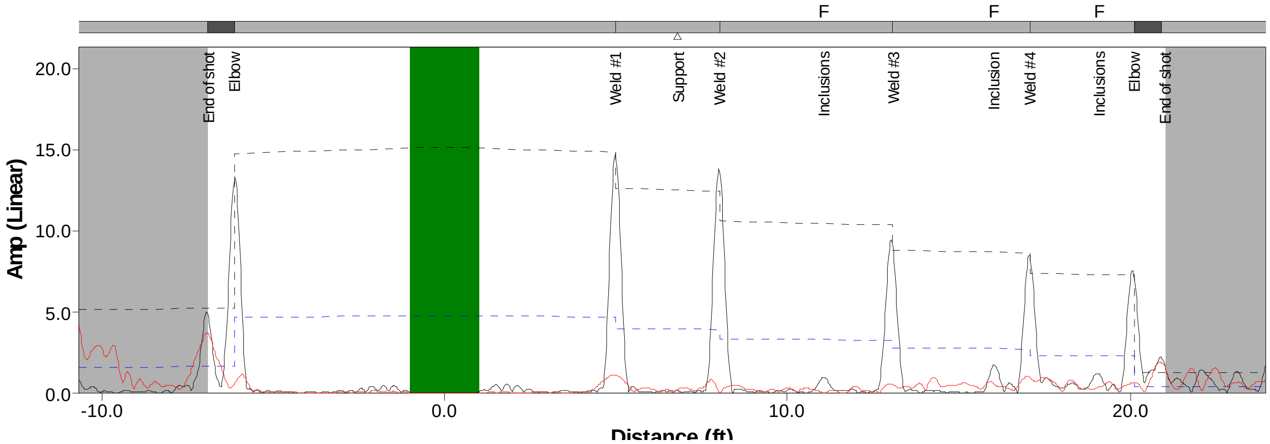


Figure 2-7
GWUT Trace from Baseline Results of Test Loop

Reflections from a Non-Symmetric Feature

A non-symmetric feature is wall loss or gain that is not uniform around the major axis of the pipe as shown in Figure 2-8. It is important to understand the responses for these types of features since most degradation is not symmetric and the understanding can assist in the interpretation of the examination results.

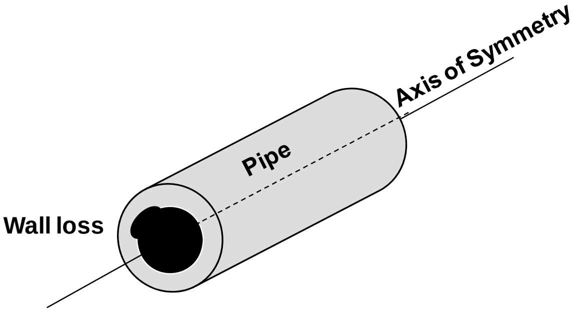


Figure 2-8
Depiction of Non-Symmetric Wall Loss of a Pipe

Reflections from such features are typically composed of both a torsional, symmetric wave and a flexural wave as shown in Figures 2-9 and 2-10.

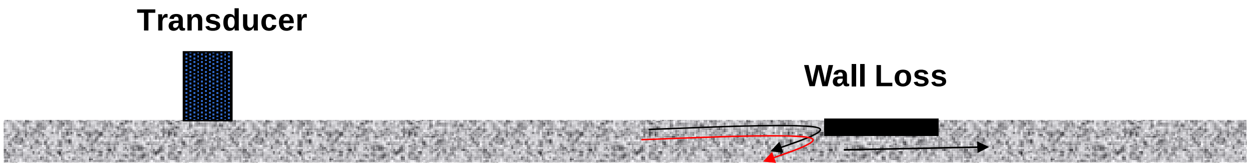


Figure 2-9
Symmetric (Black) and Non-Symmetric (Red) Responses from a Non-Symmetric Reflector

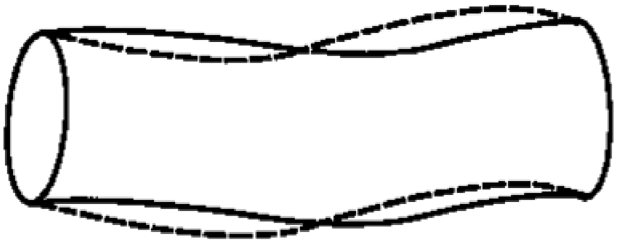


Figure 2-10
Depiction of a Flexural Wave from a Non-Symmetric Reflector

Typically, the greater the amount of non-symmetry exhibited by a feature, the greater the amplitude of the flexural response. The flexural response is depicted by a red trace. Figure 2-11 shows a comparison between a response from a symmetric girth weld and the response from a non-symmetric area of wall loss from corrosion. Note that the amplitude of the flexural response is much greater from the non-symmetric reflector.

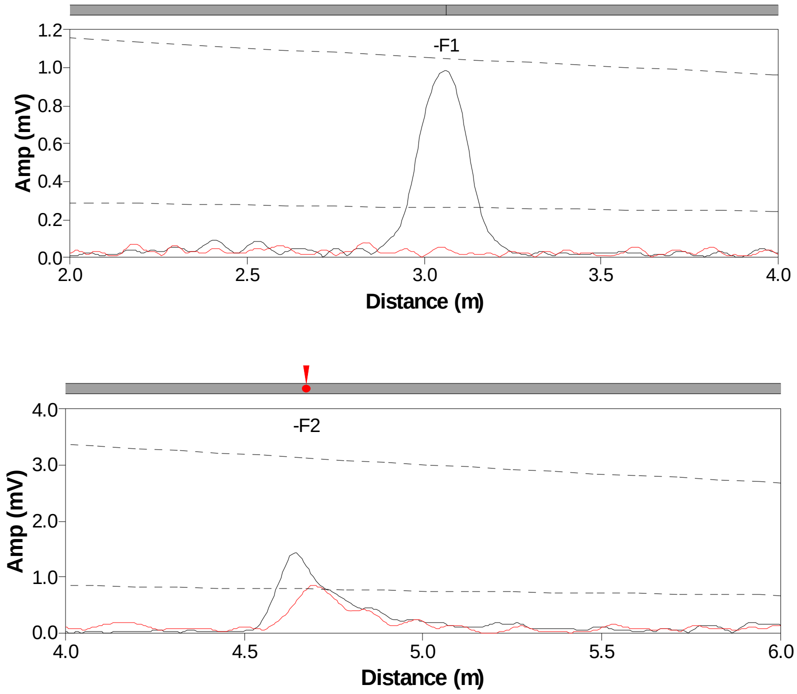


Figure 2-11
Example of Responses from Symmetric and Non-Symmetric Reflectors. Upper Graph is a Symmetrical Response from a Girth Weld and the Lower Graph is a Non-Symmetrical Response from Wall Loss Caused by Corrosion

Detection

The detection and interpretation of GWUT is generally governed by the following attributes of the examination results:

- Signal to background ratio
- The shape of the response
- The changes of the response with varying frequency and bandwidth

These attributes are discussed in the following sections.

Signal to Background Ratios

The detectability of a feature is, in part, dependent on its signal to background ratio (S/B). The S/B can be expressed as a simple ratio or in units of decibels (dB) as calculated by the following formula:

$$dB_{feature} = 10\log\frac{mV_{feature}^{2}}{mV_{bckgrnd}^{2}}$$ **Equation 1**

Where:

$dB_{feature}$ = is the S/B of the feature expressed in decibels

$mV_{feature}$ = the peak height of the feature expressed in millivolts

$mV_{bckgrnd}$ = the estimated average level of the background around the feature expressed in millivolts

The larger the S/B of a feature, the greater the detectability, when everything else remains equal. Table 2-1 provides a relative classification of S/B ratio in dB for the ease of detection. It is important to note that many factors can influence the interpretation of features in an individual examination beyond the S/B level. However, everything else being equal, the classification provides an understanding of the influence of S/B expressed in dB on the interpretability of a GWUT feature. S/B ratios were measured and used in determining the detectability of the simulated flaws in this project.

Table 2-1
Relative Classification of S/B on Ease of Detection

dB Range		**Relative Classification for ease of detection**
Low	**High**	
0.0	3.5[3]	Not detectable
3.6	10.0	Low
10.1	15.0	Medium
15.1	25.0	High
>25.1		Very High

Shape of a Response

The shape of the response is described by the amplitude, symmetry, and the relative height of the symmetric to flexural responses. A key to proper interpretation of GWUT results is recognizing

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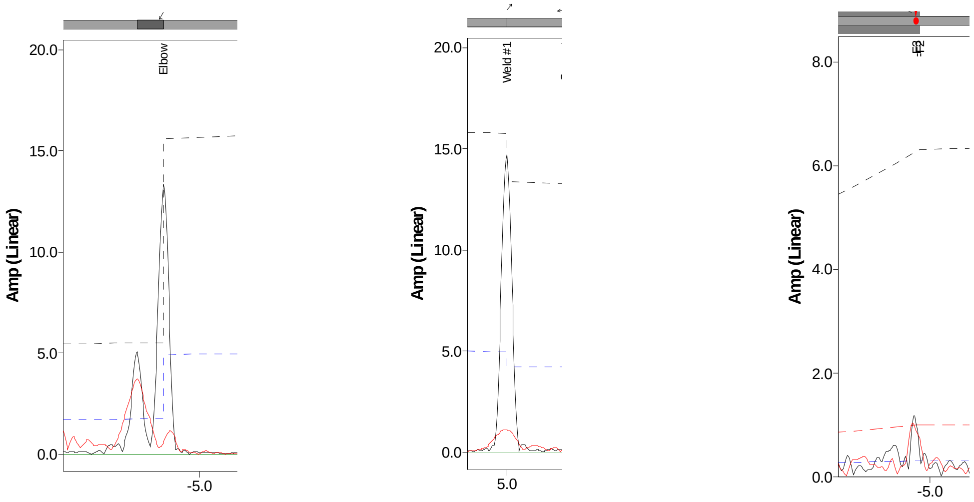
[3] Calculations have shown that an S/B ratio of 1.5 provides a 97% confidence that the indication is not a background artifact. This ratio corresponds to a dB of approximately 3.5.

the appropriate responses from different features. Figure 2-12 shows a number of responses from typical features. In this project, the patterns were used to identify FAC and crack-like features.



Elbow Weld Localized Wall Loss

Figure 2-12
Examples of Typical Response Patterns for GWUT Features

Changes of Response with Changes in Frequency

The amplitude of responses from changes in cross sectional area of the pipe, such as wall loss and welds, usually remains relatively constant for a given change in cross-sectional area as the ultrasonic frequency is varied. Amplitudes of features that are not integral with the pipe wall thickness, such as pipe supports, usually decrease as the ultrasonic frequency is increased. Understanding the various characteristics of a response with changes in frequency can aid in the interpretation of results. In this project, the responses from induced features were evaluated at various frequencies.

3

TEST LOOP

Test Loop Design

The test loop constructed for this project was fabricated from 3-inch (76-mm) schedule 40 carbon steel pipe. Ten girth welds were used to construct the loop.

Induced Flaws

Simulated flaws were induced in the test loop to simulate FAC damage and circumferential radial planar cracks. The flaws were shaped to represent actual observed damage in the field. Since GWUT is indifferent to whether the damage occurs on the inside or outside surfaces, the flaws were ground on the outside surfaces of the test loop. The FAC and planar flaws are described in the following sections and their locations shown in Figure 3-1.

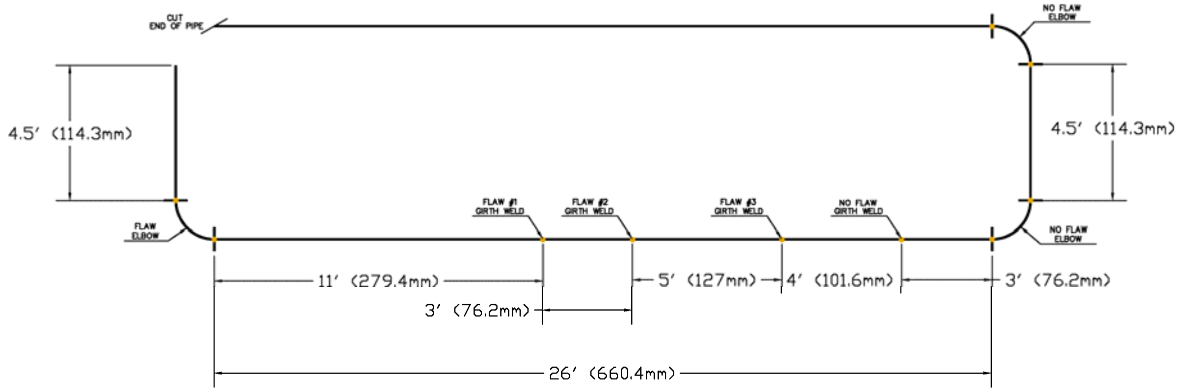


Figure 3-1
3 Inch (76 mm) Test Loop

FAC Flaws

A literature survey was conducted to identify the morphology of prevalent FAC-related damage. Three morphologies were selected and are discussed in the following sections:

Flaw #1: Circumferential Wall Loss at a Girth Weld

Flaw #1 was intended to simulate circumferential wall loss at a girth weld. A 360° groove was placed around a weld as shown in Figure 3-2. Examinations were performed when the groove was 30% and 60% of the wall thickness.

Figure 3-2
Flaw #1, 360° Groove Adjacent to Girth Weld

Flaw #2: Axially Oriented Wall Loss Associated With a Girth Weld

Flaw #2 simulates axial wall loss associated with a girth weld. This wall loss was greatest next to the girth weld and tapered off downstream of the weld. Figure 3-3 shows Flaw #2 that was 40% wall loss at the girth weld, 25% of the circumference and tapered from 40% to 0% over a 4-inch (102-mm) axial length.

Figure 3-3
Flaw #2 Simulated Axial Wall Loss Associated with a Girth Weld

Flaw #3: Wall Loss within an Elbow

Flaw #3 simulates wall loss in an elbow associated with a girth weld. Figure 3-4 shows the simulated wall loss at the elbow with similar dimensions as Flaw #2; 40% wall loss at the girth weld, 25% of the circumference and tapered from 40% to 0% over a 4-inch (102-mm) axial length.

Figure 3-4
Flaw #3, Simulated Wall Loss in an Elbow

Flaw #4: Circumferential Radial Cracking

Circumferential radial cracking is a form of degradation that can occur in or near girth welds on high temperature piping systems as shown in Figure 3-5. Two circumferential radial slits were introduced into the test loop. Flaw #4, shown in Figure 3-6, is a slit that is 30% of the circumference and 30% of the wall thickness.

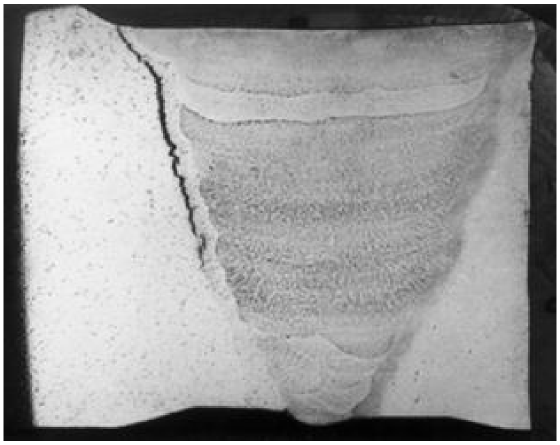


Figure 3-5
Type IV Cracking in a High Temperature Steam Line

Figure 3-6
Flaw #4, 30% around the Circumference and 30% Through Wall

4

GWUT EXAMINATION RESULTS

Examination Protocol

A baseline GWUT was conducted on the test loop prior to the introduction of FAC and circumferential cracking flaws. Five flaws were placed into the test loop per predetermined specifications. The loop was re-examined from the original baseline location. In addition, each flaw was examined with the transducer collar located such that other flaws did not interfere with the examination. This allowed for a better understanding of the response from a given flaw.

Analysis Protocol

The response from each flaw was analyzed for the following characteristics:

- Signal to Background ratio
- Signal to Background ratio change, where appropriate
- Peak shape
- Peak shape change, where appropriate
- Frequency response
- Frequency response change

In addition, a summary conclusion was made on the detectability of each flaw and actions that can improve the detectability.

Baseline Examination

Figure 4-1 shows the results of the GWUT on the test loop prior to introducing any flaws. The analysis of the examination is provided in the following sections.

Signal to Background Ratio

Table 4-1 provides the S/B for the identified features. These S/B ratios will be used to compare the affect of flaws on the S/B in other sections of the report.

Peak Shape

The girth weld and elbow responses are typical responses for such features. The welds are symmetrical with little flexural (red) response. The elbows have the typical symmetric low flexural response, with the second girth weld having a much lower response and high flexural component. For this project, the baseline examination showed that all the responses were typical and will be used as a comparison base for responses from induced flaws.

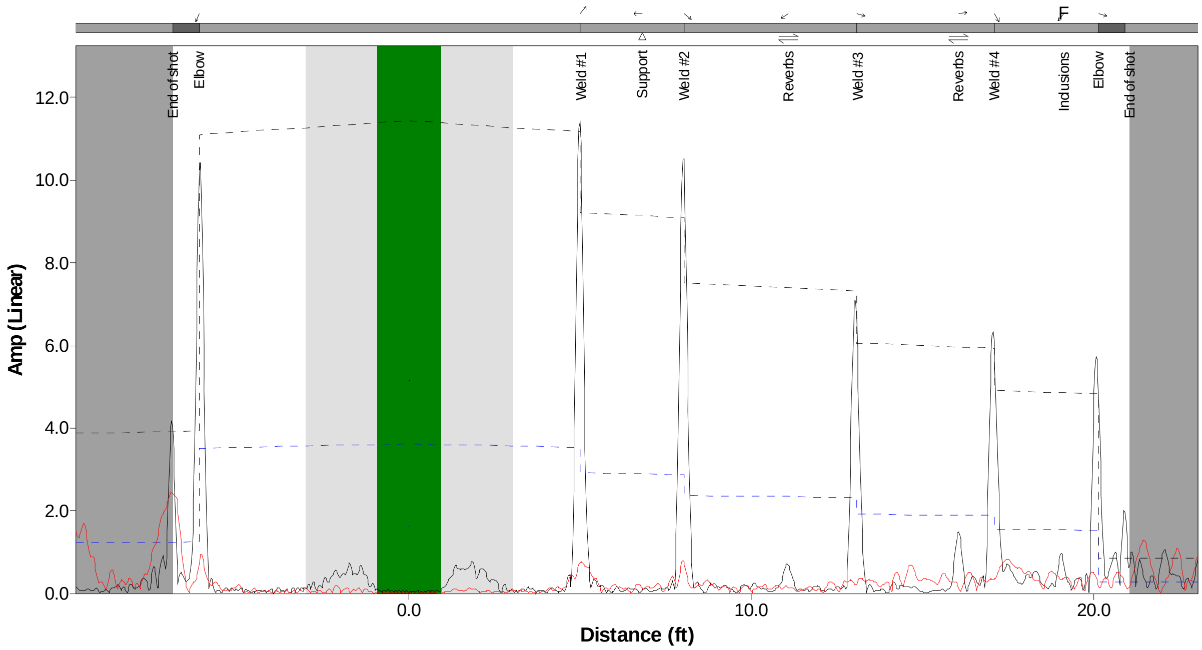


Figure 4-1
GWUT Baseline Results. Responses are Typical and Expected

Table 4-1
Signal to Background Data of Baseline Test Results

Test	Feature	Peak	Background	Ratio	dB	Corrected
Baseline	Weld 1	12.55	0.16	77.95	37.84	37.84
Baseline	Weld 2	11.70	0.16	74.05	37.39	44.77
Baseline	Weld 3	7.83	0.26	30.71	29.74	44.41
Baseline	Weld 4	7.14	0.44	16.41	24.30	44.77
Baseline	Elbow 2	6.43	0.44	14.78	23.39	48.60
Baseline	Elbow 1	11.52	0.15	77.84	37.82	37.82

Frequency Response

Table 4-2 shows the change in S/B with the change of frequency. These baseline changes in S/B will be compared to the changes of responses from flaws.

Table 4-2
Change of S/B with Changes in Frequency

Test	Feature	Optimum Freq.	High Freq.		Low Freq.	
		S/B (dB)	S/B (dB)	Delta S/B	S/B (dB)	Delta S/B
Baseline	Weld 1	37.84	37.23	0.61	26.33	-11.51
Baseline	Weld 2	44.77	38.42	6.35	30.42	-14.35
Baseline	Weld 3	44.41	48.96	-4.54	33.42	-11.00
Baseline	Weld 4	44.77	43.20	1.57	36.39	-8.38
Baseline	Elbow 2	48.60	47.80	0.81	40.30	-8.31
Baseline	Elbow 1	37.82	36.44	1.38	22.87	-14.95

Examination of Flaw #1: Circumferential Groove

Figure 3-2 shows Flaw #1 which is a circumferential groove 30% through wall, adjacent to a girth weld. It is to represent localized wall loss at a weld from FAC. Figure 4-2 shows the results from that flaw. The blue line shows the result from the baseline examination. General observation is that the amplitude of the response from the weld increased and there was an associated increase in flexural response. As expected, GWUT could not distinguish between the weld and the groove axial position.

The groove was increased in depth to 60% wall loss. Figure 4-3 shows the response from the deeper flaw with the baseline overlay.

The magnitude of the response increased dramatically as well as the flexural response. The shape of the response is still weld like except for the off centered flexural response.

Signal to Background Ratio

Table 4-3 provides the S/B ratios for Flaw #1. The change for the 30% deep flaw was a 2.12 dB increase and the change for the 60% flaw was an 8.04 dB increase. Both changes in dB are detectable. Detectability of the 30% flaw would require accurate setting of the DAC and not a lot of variation from weld to weld sizes. The detectability, based on amplitude alone, is low. The 60% through-wall depth is easily detectable from the increase in amplitude of the signal. The detectability of the flaw from amplitude alone is high.

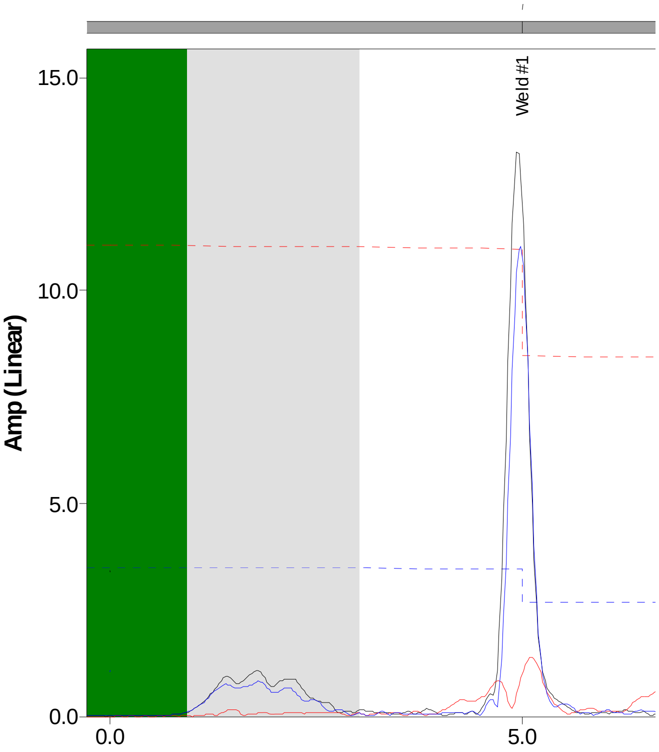


Figure 4-2
Response from Flaw #1 at 30% Wall Loss. Blue Line is Baseline Trace

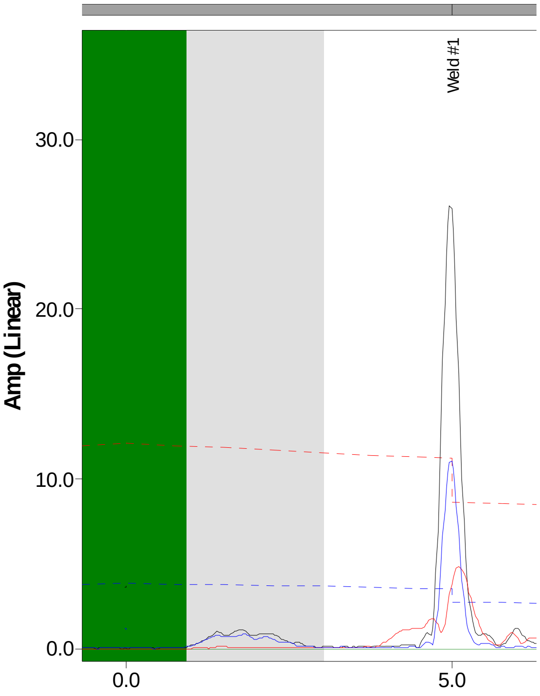


Figure 4-3
Response from Flaw #1 at 60% Wall Loss. Blue Line is Baseline Trace

Table 4-3
Signal to Background Data of Flaw #1 Test Results

Test	Feature	Peak	Background	dB	Baseline	Delta dB
Flaw #1 30%	Weld 1	13.63	0.14	39.96	37.84	2.12
Flaw #1 60%	Weld 1	26.94	0.14	45.87	37.84	8.04

Peak Shape

The symmetric response shape (black and blue) did not change a detectable amount from the baseline response as can be seen in Figures 4-2 and 4-3. However, there was an increase in the non-symmetric response (red) especially in the 60% flaw. This change in response is detectable.

Frequency Response

The responses to frequency changes are typical of a change in cross-sectional area and are shown in Table 4-4. In general, the peak amplitude decreases slightly with higher frequency. The S/B is more of a function of increasing background due to a frequency setting that was less than optimal. The change in amplitude with changing frequency would support a change in cross-sectional area as opposed to the indication being diagnosed as a support or other non-relevant feature.

Table 4-4
Change of S/B with Changes in Frequency for Flaw #1

		Optimum Frequency		High Frequency				Low Frequency			
Test	**Feature**	**Peak**	**S/B (dB)**	**Peak**	**Bkgrnd.**	**S/B (dB)**	**Delta dB**	**Peak**	**Bkgrnd.**	**S/B (dB)**	**Delta dB**
Flaw #1 30%	Weld 1	13.63	39.96	12.02	0.13	39.32	1.48	16.26	0.97	24.49	-13.35
Flaw #1 60%	Weld 1	26.94	45.87	23.37	0.33	37.00	-0.83	40.06	3.18	22.01	-15.83

Summary of Detectability of Flaw #1

In analyzing GWUT results, it is necessary to integrate all of the parameters of the response, as well as pre-assessment data, to optimize the analysis. The shape of Flaw #1 was similar to a weld and blended into the response of the adjacent weld. The detectability for this flaw is dependent on detecting the change in amplitude for the weld. At 30% through wall, the flaw was detectable but with only a minor increase in amplitude. At 60%, Flaw #1 was clearly detectable. A flaw with 30% wall loss would likely be the detectable limit for this type of flaw that coincides with or lies adjacent to a girth weld. The reason for this is that the S/B ratio for Flaw #1 is being diluted by the response from the adjacent girth weld.

Examination of Flaw #2: Axial Oriented Wall Loss Associated With a Girth Weld

Figure 4-4 shows a comparison of the response of Girth Weld #2 without a flaw (baseline case) to the weld with Flaw #2 which is shown in Figure 3-3. Flaw #2 represents 40% wall loss around 25% of the circumference, tapering back to the original wall thickness within 4 inches (100 mm).

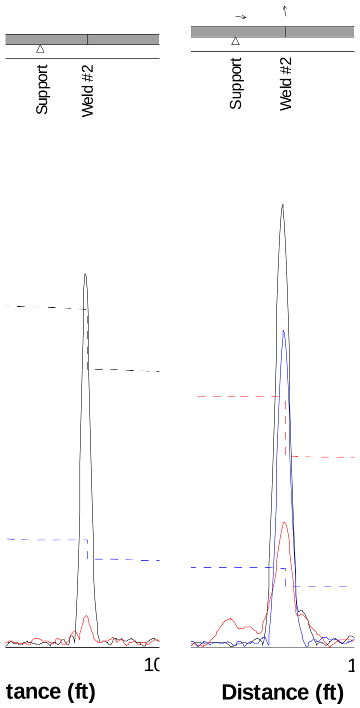


Figure 4-4
Baseline of Girth Weld (Left) Compared to Girth Weld with Flaw (Right)

Signal to Background Ratio

Table 4-5 provides the S/B ratios for Flaw #2. The change in S/B was 4.88 dB and represents an average detectability.

Table 4-5
Signal to Background Data of Flaw #2 Test Results

Test	Feature	Peak	Background	dB	Baseline	Delta dB
Flaw #2	Weld 2	16.42	0.12	42.72	37.84	4.88

Peak Shape

The general symmetric response shape (black and blue) did not change significantly from a weld other than amplitude. However, Figure 4-5 shows a secondary peak downstream of the weld. This peak is from the taper portion of the flaw. In addition the flexural (red) response has a corresponding downstream component. The change in response shape makes this feature have an average detectability with GWUT.

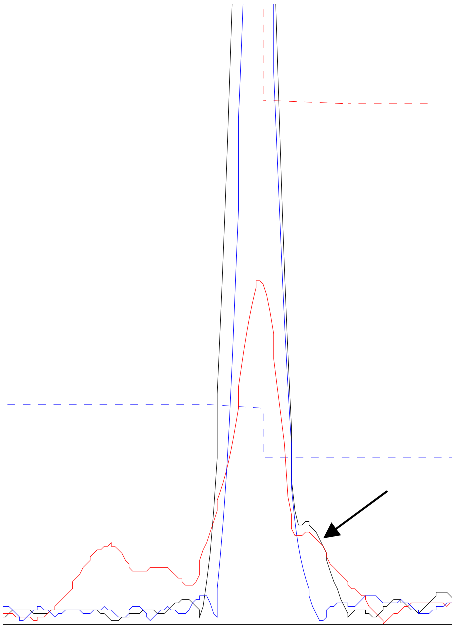


Figure 4-5
Flaw #2 (Black) Compared to Baseline (Blue). Arrow Points to Trailing Edge of Indication

Frequency Response

The responses to frequency changes are typical of a change in cross sectional area and are shown in Table 4-6. In general, the peak amplitude decreases slightly with higher frequency. The S/B is more of a function of increasing background due to a less than optimal frequency setting. The change in amplitude with changing frequency would support a change in cross-sectional area versus it being diagnosed as a support.

Table 4-6
Change of S/B with Changes in Frequency for Flaw #2

		Optimum Frequency		**High Frequency**				**Low Frequency**			
Test	**Feature**	**Peak**	**S/B (dB)**	**Peak**	**Bkgrnd**	**S/B (dB)**	**Delta dB**	**Peak**	**Bkgrnd**	**S/B (dB)**	**Delta dB**
Flaw #2	Weld 2	16.42	50.52	10.68	0.25	32.61	-10.11	33.49	1.63	26.25	-16.47

Summary of Detectability of Flaw #2

The amplitude, shape and response to frequency all support the detection of this 40% through wall flaw. It is likely that it can be detected down to 30% through wall and possibly 20%.

Examination of Flaw #3: Wall Loss in an Elbow

Figure 4-6 shows a comparison of the response from the elbow without a flaw (baseline case) to the elbow with Flaw #3 as shown in Figure 3-4. Flaw #3 represents 40% wall loss and 25% around the circumference, tapering back to original wall thickness within 4 inches (102 mm).

Signal to Background Ratio

Table 4-7 provides the S/B ratios for Flaw #3. The change in S/B for the first weld of the elbow was only 0.05 dB, which is not detectable. However, the second weld of the elbow did increase by 2.4 dB, which is marginally detectable. From amplitude measurements alone, the detectability is low.

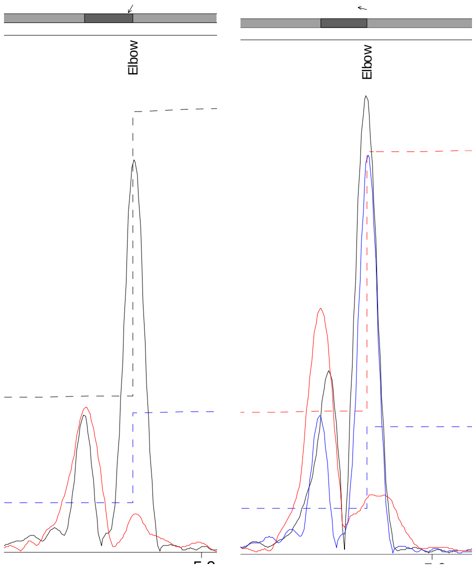


Figure 4-6
Baseline of Elbow (Left) to Elbow with Flaw (Right)

Table 4-7
Signal to Background Data of Flaw #3 Test Results

Test	Feature	Peak	Background	dB	Baseline	Delta dB
Elbow	Elbow	11.55	0.17	36.64	36.64	0.05

Peak Shape

The general symmetric response shape (black and blue) did not change significantly from a weld other than amplitude. However, Figure 4-6 shows that the response from the second girth weld moved closer to the first by 2 inches (51 mm). This shift is due to the shortening of the metal path caused by the FAC-simulated damage. In addition, the flexural response increased dramatically. The combination of the movement of the second peak and the larger flexural response makes this flaw have an average detectability, given just the shape of the peaks.

Frequency Response

The responses to frequency changes are typical of a change in cross-sectional area and are shown in Table 4-8. In general, the peak amplitude decreases slightly with higher frequency. The S/B is more of a function of increasing background due to a less than optimal frequency setting. The change in amplitude with changing frequency would support a change in cross-sectional area versus it being diagnosed as a support.

Table 4-8
Change of S/B with Changes in Frequency for Flaw #3

		Optimum Frequency		High Frequency				Low Frequency			
Test	**Feature**	**Peak**	**S/B (dB)**	**Peak**	**Bkgrnd**	**S/B (dB)**	**Delta dB**	**Peak**	**Bkgrnd**	**S/B (dB)**	**Delta dB**
Elbow	Elbow	11.55	36.64	7.89	0.11	37.11	0.47	20.57	2.87	17.11	-19.54

Summary of Detectability of Flaw #3

The small change in amplitude of the response resulted in a determination that the flaw was marginally detectable. The change in shape of the response resulted in a determination that the flaw was average detectable, with the frequency response also supporting an average detectability. Examiners will need specific training to identify this change.

Examination of Flaw #4: Circumferential Radial Cracking

Figure 4-7 compares the response of the girth weld without a flaw (baseline case) to the girth weld with Flaw #4 as shown in Figure 3-6 which is a slit 30% wall loss and 30% around the circumference.

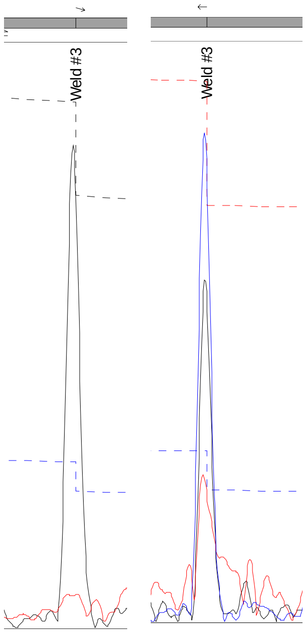


Figure 4-7
Baseline of Girth Weld without Flaw (Left) Compared to Girth Weld with Flaw (Right)

Signal to Background Ratio

Table 4-9 provides the S/B ratios for Flaw #4. The change in S/B interestingly went down with the introduction of the slit upstream of the weld. This 8 dB reduction is detectable. From amplitude measurements alone, the detectability is determined to be average.

Table 4-9
Signal to Background Data of Flaw #4 Test Results

Test	Feature	Peak	Background	dB	Baseline	Delta dB
Flaw #4	Slit	4.72	0.18	28.37	36.59	-8.22

Peak Shape

The general symmetric response shape (black and blue) did not change significantly from a weld other than amplitude. However, Figure 4-7 shows that the flexural response broadens and the amplitude increased significantly. This flexural response increase is due to the non-symmetric nature of the slit. Based on the change in the flexural response, the change in the shape of the peak signal results in a determination that the flaw has average detectability.

Frequency Response

The responses to frequency changes are typical of a change in cross-sectional area and are shown in Table 4-10. In general, the peak amplitude decreases slightly with higher frequency. The S/B is more of a function increasing background due to less than optimum frequency setting. The change in amplitude with changing frequency would support a change in cross sectional area vs. it being diagnosed as a support.

Table 4-10
Change of S/B with Changes in Frequency for Flaw #4

		Optimum Frequency		High Frequency				Low Frequency			
Test	**Feature**	**Peak**	**S/B (dB)**	**Peak**	**Bkgrnd**	**S/B (dB)**	**Delta dB**	**Peak**	**Bkgrnd**	**S/B (dB)**	**Delta dB**
Flaw #4	Slit	4.72	28.37	3.52	0.08	32.87	4.5	12.9	2.0	16.9	-12.18

Summary of Detectability of Flaw #4

The combination of the drop in amplitude and the higher flexural response lead to a determination that Flaw #4 (a radial, circumferential flaw) has average detectability.

5

CONCLUSIONS

Summary of Test Results

Three categories were used to evaluate the detectability of the flaws in the test loop. These categories were amplitude, shape, and frequency response. To more easily describe the relative detectability of the flaws, a relative score was established as shown in Table 5-1 below. Table 5-2 provides the summary of the overall detectability scores for the flaws.

Table 5-1
Detectability Score Matrix

Detectability Rating	Detectability Score
High	3
Average	2
Low	1

Table 5-2
Summary of Test Results to Determine Detectability of Flaws

Flaw #	Flaw Description	Detection Categories			Overall Detectability
		Amplitude Score	Shape Score	Frequency Score	
1	Circumferential radial wall loss adjacent to a girth weld at 30% and 60% wall loss	1	1	2	4
		3	2	2	7
2	Circumferential radial tapered patch of wall loss downstream of a girth weld	2	2	2	6
3	Circumferential radial tapered wall loss within an elbow	1	2	2	5
4	Circumferential radial slit upstream of a girth weld	2	2	2	6

Summarized Conclusions

In general, all of the flaws were detectable. In other words, all the flaw responses had discernable changes in their characteristics when compared to the baseline responses. However, the smaller the changes in flaw characteristics, the more difficult it will be to discern the flaws in the field. In all cases, having the flaws associated with a girth weld increased the difficulty in the detection. Specific FAC-related training of the GWUT technician will improve the overall reliability of the examination results.

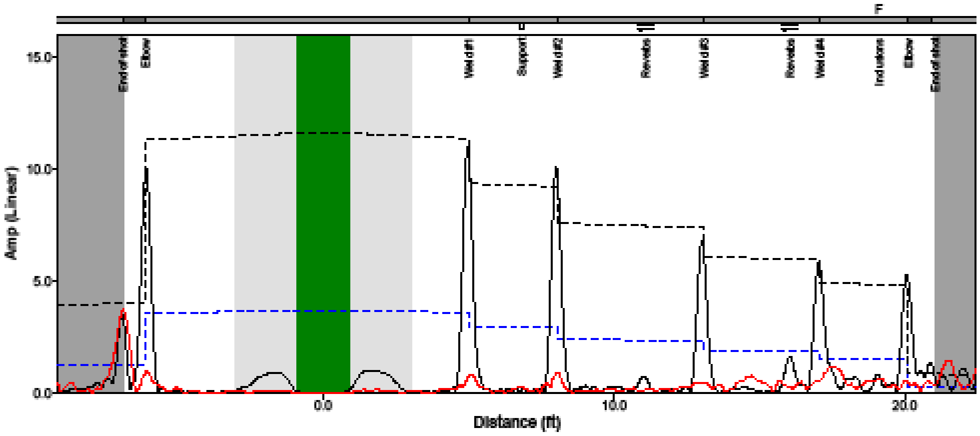
A

APPENDIX GWUT REPORTS

Pipe:	3" Test loop PRCI	Ring:	R2F03(142)
Site:	SI Lab	Config:	1.8FR, T(0,1)
Location:	Support -1'	Calibration:	Automatic (747.639 mV)
Size:	3 inch (.190")	Version:	3.96, Wavemaker G3-120
Tested:	16 Dec 2008 12:50	Client:	EPRI
Tested by:	Craig Chaney [Strlty]	Procedure:	GU 1.1
		DACs:	Call=7%, Weld=23%

General Notes: Baseline shot with eight channel collar at S-5 location

Feature	Location	Size (mV)	ECL	Extent	Class	Notes
Elbow	-6'1"	10.1	-	90	Bend	
Weld #1	5'0"	11	-	90	Weld	
Support	6'10"	0.185	-	0	Support	
Weld #2	8'0"	10.1	-	90	Weld	
Reverbs	11'1"	0.697	-	80	Reverb.	
Weld #3	13'1"	6.77	-	90	Weld	
Reverbs	16'0"	1.58	-	70	Reverb.	
Weld #4	17'1"	5.84	-	90	Weld	
Inclusions	19'1"	0.832	-	25	Other	
Elbow	20'1"	5.32	-	90	Bend	
End of shot	21'0"	1.37	-		End	
End of shot	-6'11"	3.5	-		End	



3&22_Test_loop_PRCI-Support-=1&27-T7-G0120#1547-cc.wg3

Pipe: Test Loop EPRI
Site: SI Lab
Location: Support -1'
Size: 3 inch

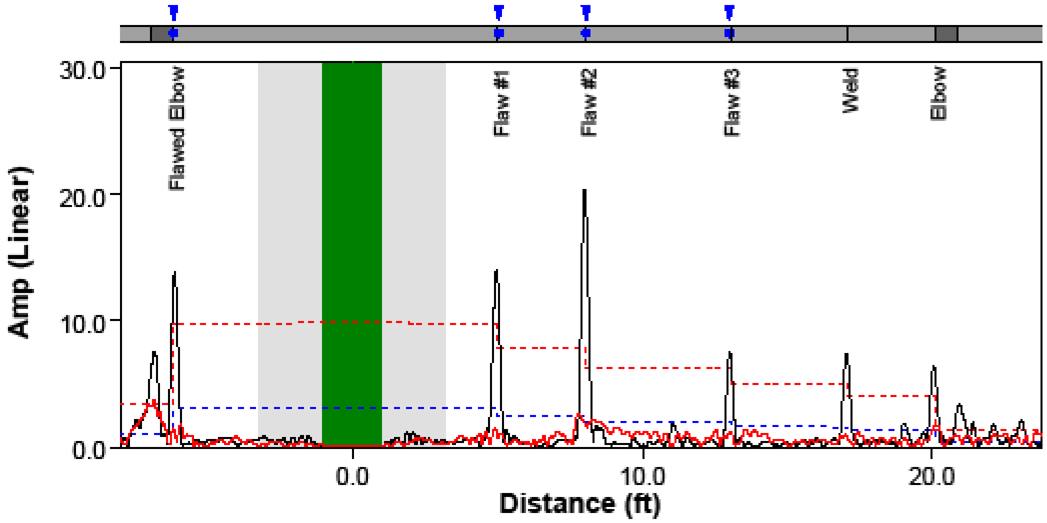
Tested: 15 Jan 2009 17:15
Tested by: Larry Weigel[Strlt]

Ring: R2F03(1271)
Config: 0.2FR, T(0,1)
Calibration: Automatic (836.181 mV)
Version: 3.96, Wavemaker G3-30

Client: EPRI
Procedure: GU 1.1
DACs: Call=7%, Weld=23%

General Notes: Shot take after the induced flaws and S-4 location

Feature	Location	Size (mV)	ECL	Extent	Class	Notes
Flawed Elbow	-6'2"	13.8	-	90	1D Bend	
	-6'2"	13.8	70	90	Medium	
	4'12"	14	30	90	Weld	
Flaw #1	5'0"	14	40	90	Medium	
Flaw #2	8'0"	20.3	60	90	Medium	
Flaw #3	12'12"	7.56	25	80	Medium	
Weld	17'1"	7.42	35	90	Weld	
Elbow	20'1"	6.37	-	70	1D Bend	



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Pipe: Test Loop
Site: Cerritos Lab
Location: Support -1'
Size: 3 inch (.190")

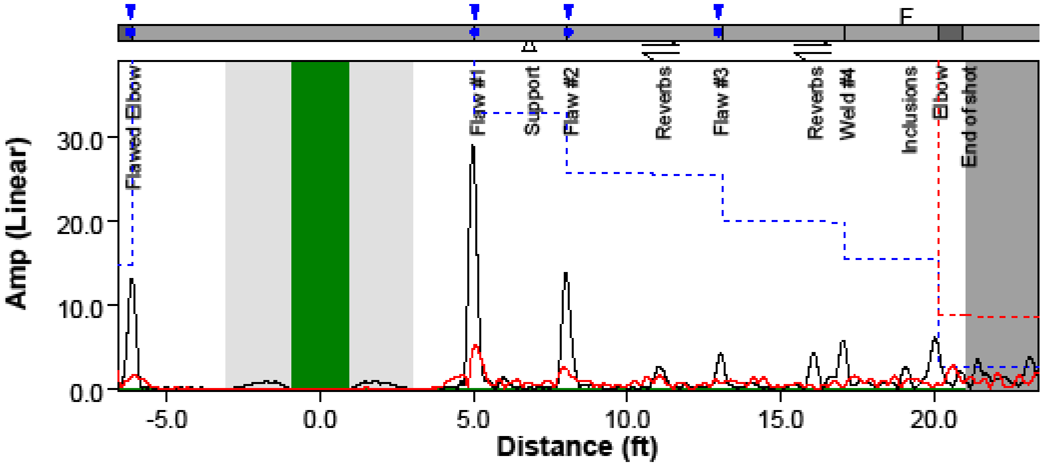
Tested: 15 Jan 2009 20:07
Tested by: Craig Chaney [Strlty]

Ring: R2F03(1271)
Config: 1.2FR, T(0,1)
Calibration: Automatic (954.568 mV)
Version: 3.96, Wavemaker G3-30

Client: EPRI
Procedure: GU 1.1
DACs: Call=7%, Weld=23%

General Notes: This shot was taken after the circumferential groove at the first weld was increased in depth to .100"

Feature	Location	Size (mV)	ECL	Extent	Class	Notes
Flaw #1	5'0"	28.9	7	80	Medium	
Support	6'10"	0.179	-	0	Support	
Flaw #2	8'1"	13.8	4	80	Medium	
Reverbs	11'1"	2.43	-	45	Reverb.	
Flaw #3	12'11"	4.24	1	70	Medium	
Reverbs	16'0"	4.06	-	90	Reverb.	
Weld #4	17'1"	4.98	-	80	Weld	
Inclusions	19'1"	2.6	-	50	Other	
Elbow	20'1"	5.23	-	90	Bend	
End of shot	21'0"	1.84	-		End	
Flawed Elbow	-6'2"	13.2	7	90	Medium	
End of shot	-6'11"	5.64	-		End	



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