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under Contract DE-AC05-76RL01830

Evaluation of Ultrasonic Time-of-Flight Diffraction Data for Selected Control Rod Drive Nozzles from Davis Besse Nuclear Power Plant

SE Cumblidge
AD Cinson
MT Anderson

April 2010

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Summary

Pacific Northwest National Laboratory (PNNL) examined ultrasonic (UT) time-of-flight diffraction (TOFD) data from ten (10) nozzles in the Davis Besse Nuclear Power Plant reactor closure head. The TOFD data was acquired by AREVA after a bare metal visual examination of the pressure vessel head indicated potential leakage in at least one nozzle. A detailed analysis of the UT data shows that Nozzle 4 has three indications consistent with cracking in the penetration tube. One of the indications starts at the wetted side of the weld and progresses to the annulus. In addition, examination of UT data from the annulus region of Nozzle 4 displays an irregular pattern that could be associated with boric acid deposits and leakage/wastage in the interference fit.

The review of TOFD data for the other nine nozzles resulted in several indications being detected in the weld region and near the inner diameter (ID) and outer diameter (OD) surfaces of the penetration tube, but no other indications that are consistent with cracking that may have resulted in leakage were observed. A review of the back-wall reflections in the other nine nozzles also did not show strong indications of leakage, although Nozzle 67 displayed an irregularly-shaped region of high ultrasonic transmission near 180 degrees on the interference fit.

Acronyms and Abbreviations

AOCF	axial orientation to detect circumferential flaws
COAF	circumferential orientation to detect axial flaws
CRDM	control rod drive mechanism
ID	inner diameter
LOS	loss of signal
NDE	nondestructive examination
NRC	U.S. Nuclear Regulatory Commission
OD	outer diameter
PINC	Program for the Inspection of Nickel Alloy Components
PNNL	Pacific Northwest National Laboratory
PWSCC	primary water stress corrosion cracking
RPV	reactor pressure vessel
TOF	time of flight
TOFD	time-of-flight diffraction
UT	ultrasonic

Contents

Summary iii
Acronyms and Abbreviations v
1.0 Introduction 1.1
2.0 TOFD Data Analyses 2.1
2.1 Nozzle Number 4 .... 2.1
2.2 Nozzle Number 12 .... 2.6
2.3 Nozzle Number 19 .... 2.8
2.4 Nozzle Number 40 .... 2.11
2.5 Nozzle Number 42 .... 2.12
2.6 Nozzle Number 48 .... 2.14
2.7 Nozzle Number 57 .... 2.16
2.8 Nozzle Number 60 .... 2.18
2.9 Nozzle Number 66 .... 2.20
2.10 Nozzle Number 67 .... 2.23
3.0 Summary 3.1
4.0 Conclusions 4.1
5.0 References 5.1

Figures

1.1 Control Rod Drive Nozzle Diagram ... 1.2
2.1 Deep TOF-Shaped Indications in Nozzle 4 ... 2.1
2.2 COAF data - Indication Positions and Weld Location in Nozzle 4 ... 2.2
2.3 Back Wall and Weld Signals Near the Three Axial Indications in Nozzle 4 ... 2.3
2.4 Responses from the Three Indications Using the AOCF Probes in Nozzle 4 ... 2.4
2.5 Indications in Nozzle 4 Using the AOCF Probes ... 2.4
2.6 Indication in the Weld at 263 Degrees in Nozzle 4 ... 2.5
2.7 Irregular Region of Variable Ultrasonic Transmission in Nozzle 4 ... 2.6
2.8 COAF Data Showing Two Indications in Nozzle 12 ... 2.7
2.9 AOCF Data Showing Indication at 240 Degrees in Nozzle 12 ... 2.7
2.10 Reduced-Amplitude Indications in the COAF Lateral Wave of Nozzle 19 ... 2.8
2.11 AOCF Data Showing TOF Shape Indications in Nozzle 19 ... 2.8
2.12 Non-TOF-Shaped Responses Found in Nozzle 19 ... 2.9
2.13 Indications Found in the J-groove Weld Region of Nozzle 19 ... 2.9
2.14 AOCF Data Showing Strong TOF Shape Indication in Weld Region of Nozzle 19 ... 2.10
2.15 AOCF Data Image Showing Reduced Amplitude in the Interference Fit Region of Nozzle 19 ... 2.10
2.16 Shallow OD Indication in Nozzle 40 ... 2.11
2.17 AOCF Data Showing a Series of TOF Shape Indications in the Weld Region of Nozzle 40 ... 2.12
2.18 AOCF Data Showing Indications in the Weld Region in Nozzle 42 ... 2.13
2.19 Side Views of AOCF Data Showing Possible Penetration into Tube Wall of Nozzle 42 ... 2.13
2.20 Side View of AOCF Data Showing TOF Shape Indication in Lower Middle Region of the Tube of Nozzle 48 ... 2.14
2.21 AOCF Data Showing Indications in the Weld Region of Nozzle 48 ... 2.15
2.22 AOCF Data Showing Indications Across the Weld Region Around 17 Degrees in Nozzle 48 ... 2.15
2.23 Side View of AOCF Data Showing TOF Indications Above Weld Region of Nozzle 48 ... 2.16
2.24 ID Indications Found in the Penetration Tube of Nozzle 57 ... 2.17
2.25 "X"-Shaped Indications in the Penetration Tube ... 2.17
2.26 Weld Intrusions in Nozzle 57 ... 2.18
2.27 Weld Indications in Nozzle 60 ... 2.19
2.28 Weld Indications in Nozzle 60 ... 2.19
2.29 TOF Shapes Showing the Weld Intrusion into the Penetration Tube of Nozzle 60 ... 2.20
2.30 COAF Indications with TOF Shapes Found in Nozzle 66 ... 2.20
2.31 AOCF Indications with TOF Shapes Found in Nozzle 66 ... 2.21
2.32 TOF Shapes for the Four Indications in Nozzle 66 ... 2.22
2.33 Region of Reduced Amplitude in the Interference Fit of Nozzle 66 ... 2.23
2.34 Weld Indication in Nozzle 67 ... 2.23

2.35 TOF Shapes Visible on the OD of the Penetration Tube of Nozzle 67 .... 2.24
2.36 Region of Reduced Amplitude Near 180 Degrees 2.24

Tables

2.1 Axial Indication Lengths and Positions in Nozzle 4 .... 2.3
3.1 Summary of PNNL Review of Davis Besse TOFD Data 3.1

1.0 Introduction

Pacific Northwest National Laboratory (PNNL) performed an independent review of ultrasonic (UT) time-of-flight diffraction (TOFD) data acquired in the field from ten Davis Besse Nuclear Power Plant (Davis Besse) control rod drive mechanism (CRDM) nozzles. At the request of the U.S. Nuclear Regulatory Commission (NRC), this data was provided to PNNL by the licensee's contractor, AREVA. AREVA had conducted a series of TOFD examinations of the CRDM penetrations in the Davis Besse reactor vessel closure head after boric acid residue from apparent leakage had been detected on the outside surface of the head.

The control rod drive penetrations in the Davis Besse closure head consist of an Alloy 600 tube that is set in a cylindrically-drilled hole in the low-alloy carbon steel head. The penetration tube and surrounding carbon steel are fabricated in a condition called an "interference fit," where the penetration tube is slightly larger than the hole drilled through the steel head. The penetration tube is typically cooled with liquid nitrogen to thermally shrink the tube for installation, where it subsequently warms and increases in size to become firmly held in place by the carbon steel. While this interference fit provides significant structural support, it is not necessarily water-tight, especially when the reactor is at operating temperature and pressure. To ensure a water-tight seal, a partial penetration "J-groove" weld is made at the inner surface of the carbon steel head and CRDM penetration tube. This weld is typically 1 to 2 inches thick. A layer of Alloy 182 "buttering" is welded to the carbon steel prior to welding the remaining Alloy 182 filler material in order to facilitate an effective bond. A diagram of a typical CRDM is shown in Figure 1.1.

The commonly accepted method of describing the coordinate system in a CRDM weld is to set the zero degree coordinate at the radial point farthest away from top-dead-center of the closure head. This puts the zero-degree point at the lowest point in the weld. The 180-degree point is then at the highest part of the weld, which points directly at the center of the closure head.

While TOFD data on the penetration tubes were supplied to PNNL, the TOFD scans only penetrate a short distance into the J-groove welds, and thus very limited information on the J-groove weld was provided. To fully assess these welds, volumetric and wetted surface nondestructive examination (NDE) information targeted specifically for the weld volumes would be needed. For instance, eddy current scans of the J-groove weld wetted surface would be very useful in determining if cracking in the Alloy 182 weld materials may be present.

PNNL reviewed the AREVA TOFD UT (Key 2010) procedure to ascertain the manner and orientation in which data were acquired. TOFD data was taken with separate probes configured in two orientations to detect either axial or circumferential flaws in the CRDM penetration tubes. The first orientation is referred to as "Axial Orientation to detect Circumferential Flaws" or AOCF. The second orientation is "Circumferential Orientation to detect Axial Flaws" or COAF. Thus, one would expect the COAF data to have the highest sensitivity and most accurate sizing capabilities for axially-oriented flaws, while the AOCF to be the most effective at detecting and characterizing circumferentially-oriented flaws.

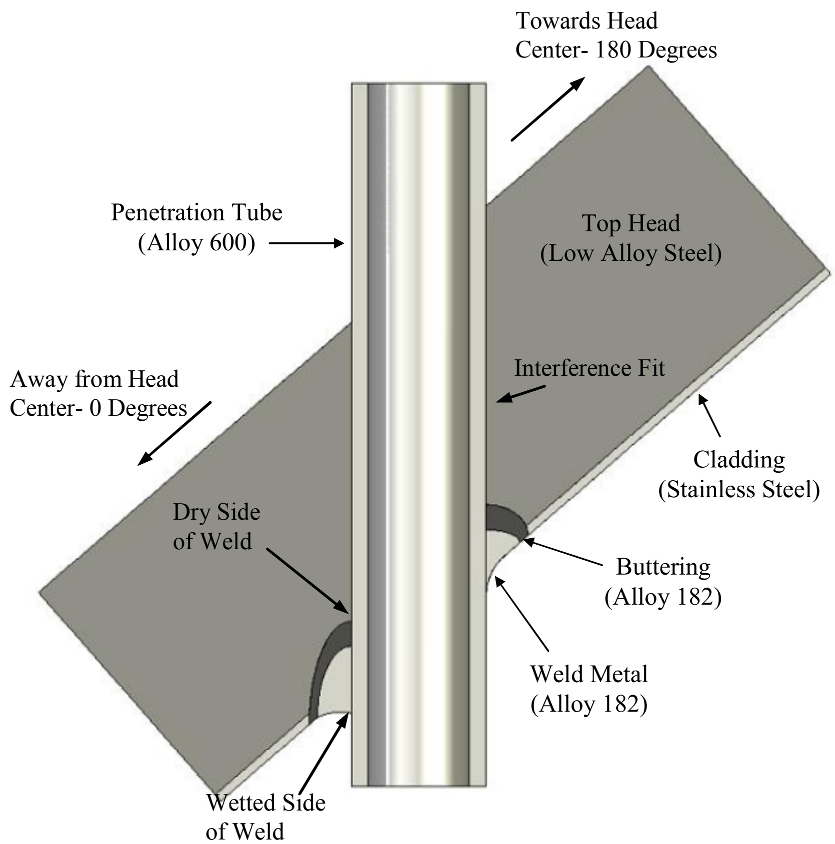

Figure 1.1. Control Rod Drive Nozzle Diagram

Previous experience with CRDM welds has shown that fabrication anomalies often exist in the J-groove weld. These "fabrication flaws" are typically embedded, not associated with service degradation, and generally do not grow to cause leakage. Welding flaws can include conditions such as lack of fusion, porosity, or slag inclusions. These flaws often follow the weld passes and may appear as a string of indications aligned in the welding direction, or may be located (stacked) along the fusion areas of the weld. These flaws can provide strong acoustic reflections from the weld region and may result in UT indications that can be misidentified as related to service degradation; i.e., primary water stress corrosion cracking (PWSCC). Another fabrication condition that can result in indications is a weld intrusion. A weld intrusion is caused by the welding process removing an unusual amount of material from the penetration tube. It can be caused by the normal welding process or in a region that was repaired during fabrication of the J-groove weld. Each indication found in the Davis Besse data supplied by AREVA was evaluated to determine if it was consistent with cracking, or with welding flaws, to minimize misinterpreting these as PWSCC.

Stephen Cumblidge holds a Ph.D. in Nuclear Engineering and has been researching the use of nondestructive techniques such as phased-array ultrasound, TOFD, and eddy current, for detecting and characterizing flaws in nuclear power plant components for six years, with duties ranging from hands-on data collection and analysis to project management. He was the primary investigator for the nondestructive and destructive characterization of removed-from-service control rod drive mechanisms from the North Anna 2 reactor pressure vessel head and the lead author on NUREG/CR-6996 (Cumblidge et al. 2009) describing the results of this work. Dr. Cumblidge also managed the Program for the Inspection of Nickel Alloy Components (PINC), which explored the effectiveness of various NDE techniques for detecting and characterizing flaws in Alloys 600 and 82/182.

Anthony Cinson is a PNNL Research Scientist. He holds a B.S. in Physics. His current work responsibilities and interests include NDE applications with a focus on experimental design, acquisition, and analysis of phased-array UT data, and application of various other NDE techniques for materials characterization and structural integrity assessments. Mr. Cinson is involved in the development of advanced ultrasonic prototype technologies

Michael Anderson is a recognized expert in NDE, with over 30 years of experience in the application and analyses of varied NDE methods for inservice inspections of nuclear power plant materials and components. He has a B.S. in NDT Science and an M.S. in Metallurgy, and holds international Level III certifications in ultrasonics, radiography, liquid penetrant and magnetic particle testing, and visual examination methods. Mr. Anderson is a Fellow of the American Society for Nondestructive Testing.

Each nozzle evaluation is described in detail and the relevant indications are shown and discussed in Section 2. In Section 3 the results are summarized and discussed. The conclusions based on PNNL analyses are given in Section 4. References are provided in Section 5.

2.0 TOFD Data Analyses

Each data set from the ten nozzles was examined in detail to determine if there were any ultrasonic signals indicative of flaws that could result in leakage, or if there was any sign of a leakage path in the ultrasonic response in the interference fit area. The TOFD data was gated at the penetration tube inner diameter (ID) to look for breaks in the lateral wave. Second, the data was gated around the tube outer diameter (OD) to look for breaks in the back-wall response. The data was then gated to search for time-of-flight (TOF) shapes in the middle of the penetration tube to search for responses from crack tips. Finally, the interference fit region was examined for ultrasonic transmission or reflectance levels, which could indicate boric acid deposits or a potential leakage path.

2.1 Nozzle Number 4

PNNL has reviewed the TOFD data, and it has been determined that there is an axial indication that progresses through the penetration tube to the annulus region, providing a potential leakage path. Two additional long axial indications appear to have propagated almost the entire width of the weld.

When the data is gated to allow an examination of the lateral wave in the AOCF and COAF data, there is no sign of any indications breaking the ID surface of the penetration tube. However, there is a marked decrease in the amplitude of the lateral wave in the COAF data over the weld. This decreased amplitude may be caused by weld shrinkage causing the ID of the tube to contract in the weld region, resulting in reduced coupling between the circumferential blade probes and the tube surface.

When the data is gated in the middle of the penetration tube, three axial indications are visible. The three indications are located at 346–8 degrees, 43–71 degrees, and from 75–93 degrees. All three indications are located in the weld region of the nozzle. The three indications have clear TOF shapes in the penetration tube. They originate in the penetration tube OD. The TOF shapes are shown in Figure 2.1.

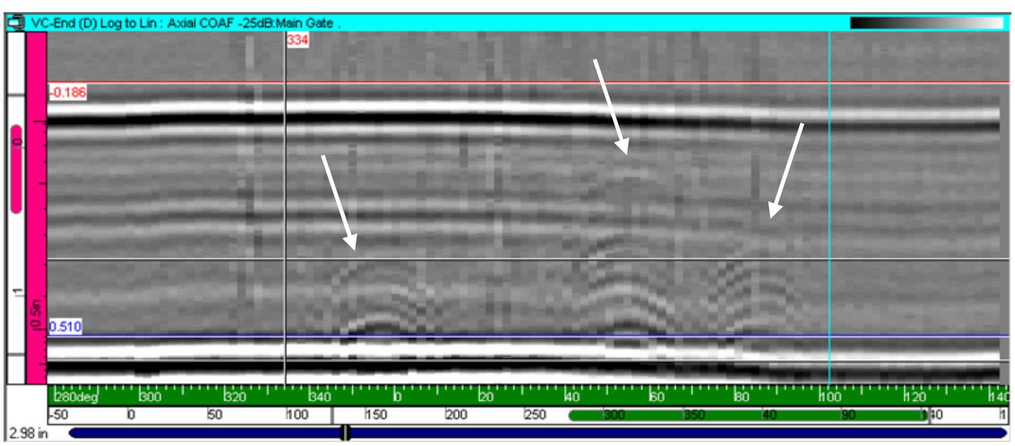

Figure 2.1. Deep TOF-Shaped Indications in Nozzle 4

Using the COAF data, one can get an idea of the length of the indications and the weld extent. The ends of the indications appear to have higher amplitudes than the middles, although there are discernable TOF shapes across the entire indication connecting the higher amplitude ends. The lengths and positions of the indications are shown in Figure 2.2, with the edge of the weld region shown in gray (weld region adjacent to tube is in blue, as viewed from the inside of the penetration tube looking out). Indication 1 appears to start on the wetted side of the penetration tube and end in the middle of the weld. Indication 2 appears to cut across the entire weld region. Indication 3 appears to start in the middle of the weld and end on the dry side of the weld.

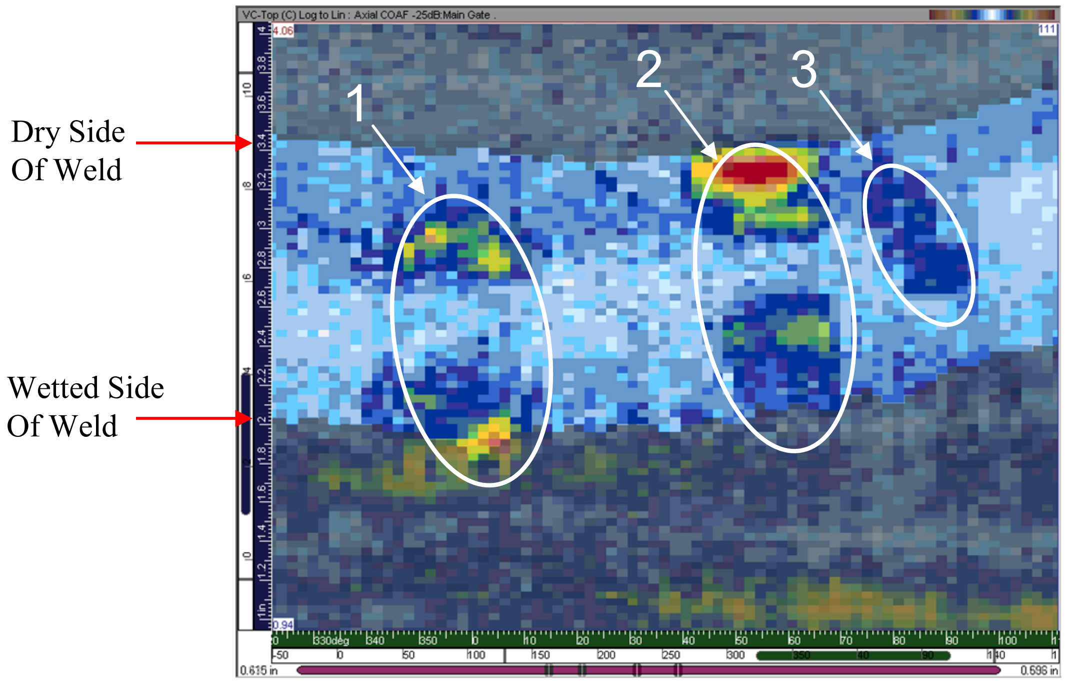

Figure 2.2. COAF data - Indication Positions and Weld Location in Nozzle 4

When the data is gated at the OD of the tube, no indications in the weld are coincident with the axial indications in the penetration tube. There is a disruption of the back wall associated with indication 1 at the dry end of the weld, with no clear back-wall disruption associated with indications 2 or 3. The lack of indication in the weld regions and the disruptions in the back-wall responses are shown in Figure 2.3.

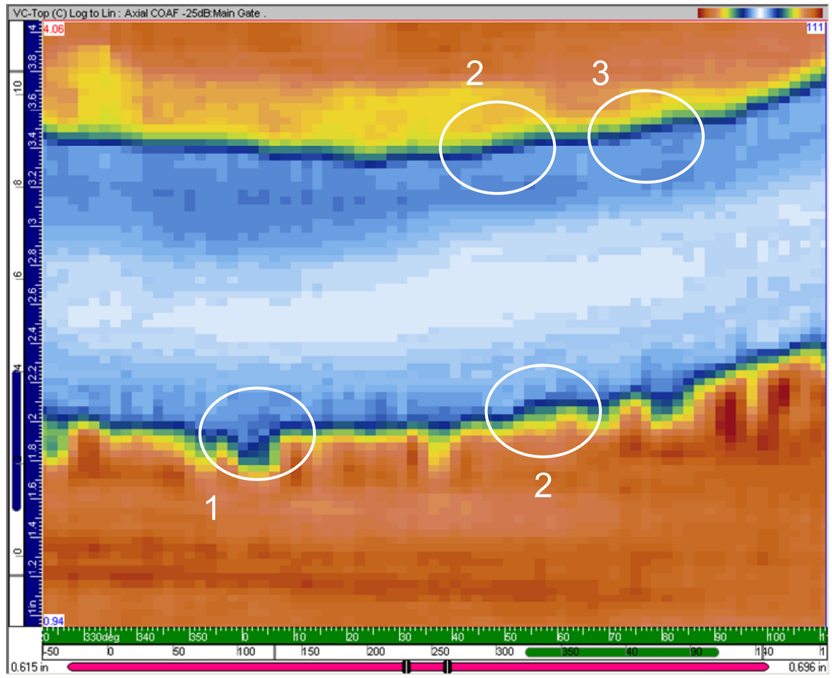

Figure 2.3. Back Wall and Weld Signals Near the Three Axial Indications in Nozzle 4

The lengths and positions of the three indications were examined to determine the indication lengths and positions using the TOF shapes detected in the COAF data. The axial indications were examined in detail to determine their start and end points, and this was correlated with the apparent weld starting and ending points. The TOF shapes were measured using the loss-of-signal (LOS) sizing technique. The results are shown in Table 2.1.

Table 2.1. Axial Indication Lengths and Positions in Nozzle 4

Indication	LOS Start	LOS End	Weld Start	Weld End	Depth (in.)	Depth %
1	1.75	3.17	2.01	3.39	0.27	0.54
2	2.13	3.46	2.13	3.43	0.30	0.60
3	2.57	3.31	2.24	3.54	0.15	0.30

The LOS examination concurs with the earlier figures. Indication 1 begins in the penetration tube OD on the wetted side of the weld but stops in the weld region. Indication 2 crosses the weld. Indication 3 starts in the middle of the weld and ends on the dry side of the weld.

The AOCF data shows the three axial indications in detail, without the amplitude drop region in the middle of the indications. This is interesting, as the AOCF scans are optimized for circumferential flaws, not axial flaws. Indication 2 shows a circumferential component not visible in the COAF data (see Figure 2.2). Based on these responses, one can infer that the three indications have a complex structure, possibly including branching, to cause these clear responses using the axially-oriented probes. The responses for the AOCF indications are shown in Figure 2.4. The responses with the weld location are shown in

Figure 2.5. The AOCF data shows a similar indication profile for indications 1 and 2, but it locates indication 3 closer to the wetted side of the weld.

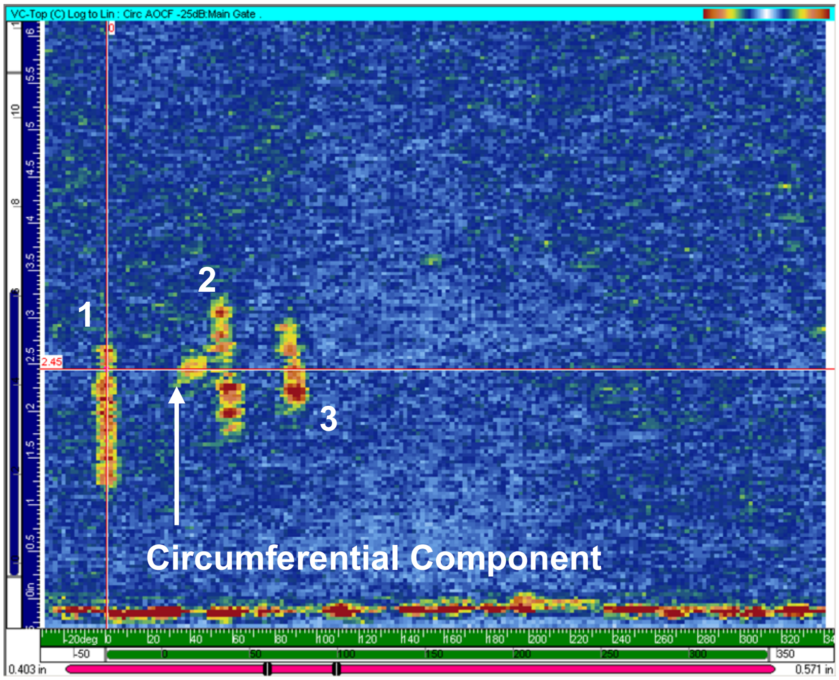

Figure 2.4. Responses from the Three Indications Using the AOCF Probes in Nozzle 4

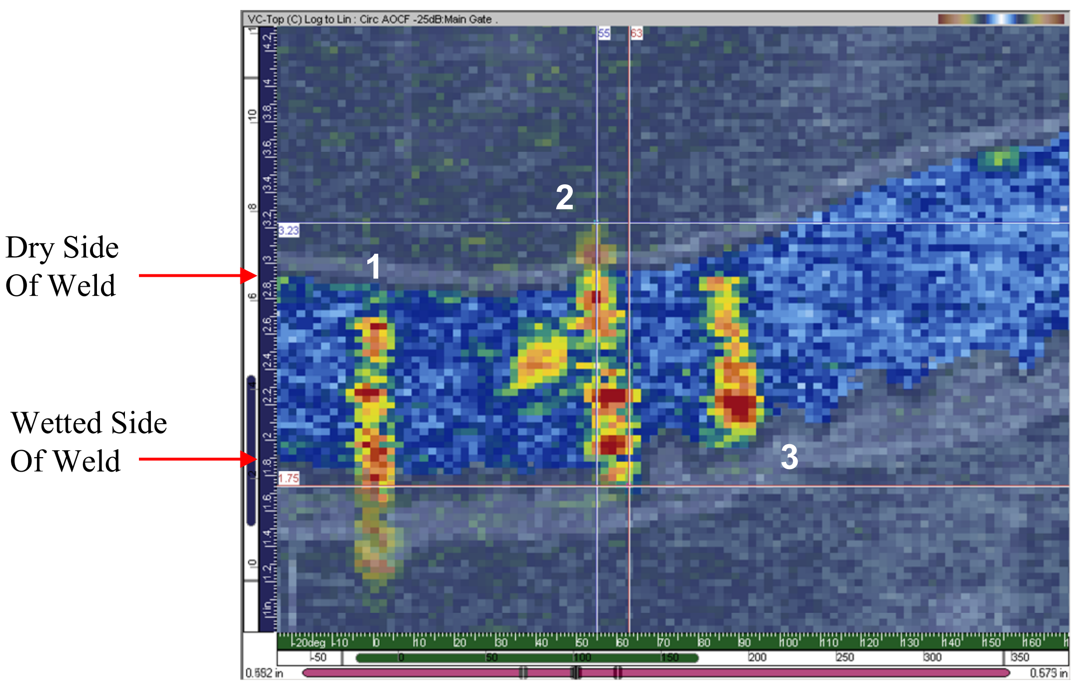

Figure 2.5. Indications in Nozzle 4 Using the AOCF Probes

One weld indication was found using the AOCF scans. This weld indication protrudes slightly into the penetration tube, but does not appear to be an axial crack and does not intersect with either weld boundary. The weld indication is shown in Figure 2.6.

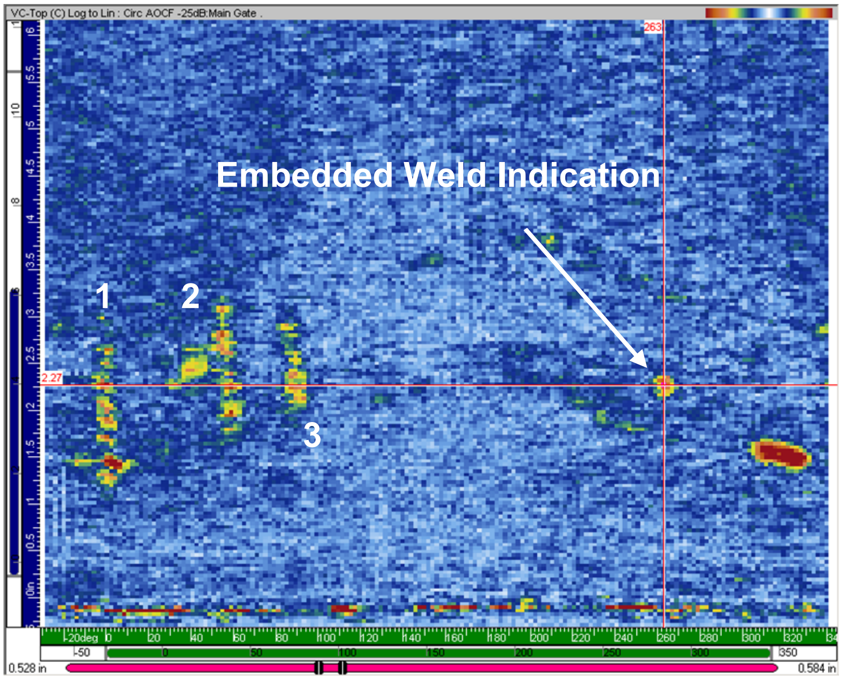

Figure 2.6. Indication in the Weld at 263 Degrees in Nozzle 4

A large region of the interference fit shows signs of having boric acid deposits, characterized by an irregularly-shaped region with variable transmission of ultrasound. The region starts at 156 degrees and ends at 71 degrees. This region is similar to the pattern seen in North Anna 2 Nozzle 31 (Cumblidge et al. 2009), which on destructive examination showed boric acid deposits with a similar shape as the regions with high ultrasonic transmission. The region of variable transmission is shown in Figure 2.7.

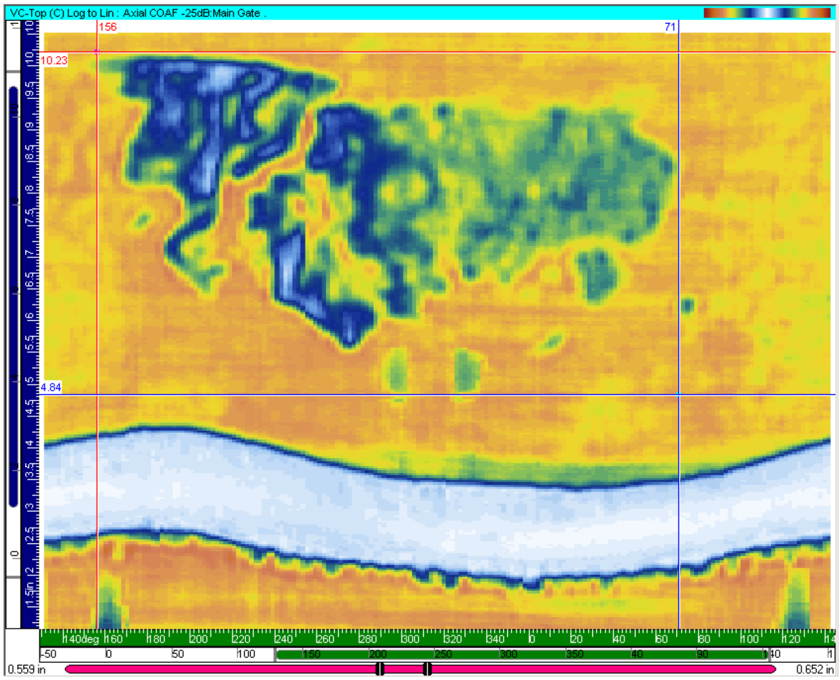

Figure 2.7. Irregular Region of Variable Ultrasonic Transmission in Nozzle 4

2.2 Nozzle Number 12

When the COAF and AOCF data is gated to examine the lateral wave, no breaks in the lateral wave were found. This consistent lateral wave in both orientations shows no evidence of a crack breaking the ID surface of the penetration tube.

When COAF data was gated around the interior of the penetration tube, two indications with TOF shapes were found. Both indications were very near the OD of the tube and at the wetted and dry edges of the weld region. The first indication occurs at 238 degrees circumferentially in the lower (wetted) side of the weld while the indication at 248 degrees appears in the upper (dry) side of the weld. No ultrasonic reflections were found between these two indications, suggesting that they are not connected. Both indications are visible in the COAF data and are shown in Figure 2.8. The indication at 248 degrees is also apparent in the AOCF data and is shown in Figure 2.9.

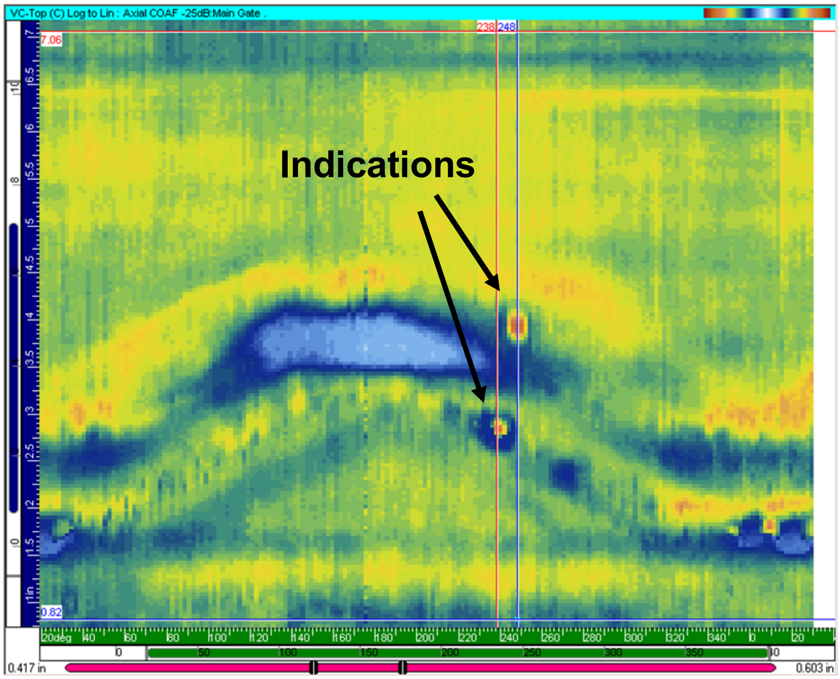

Figure 2.8. COAF Data Showing Two Indications in Nozzle 12

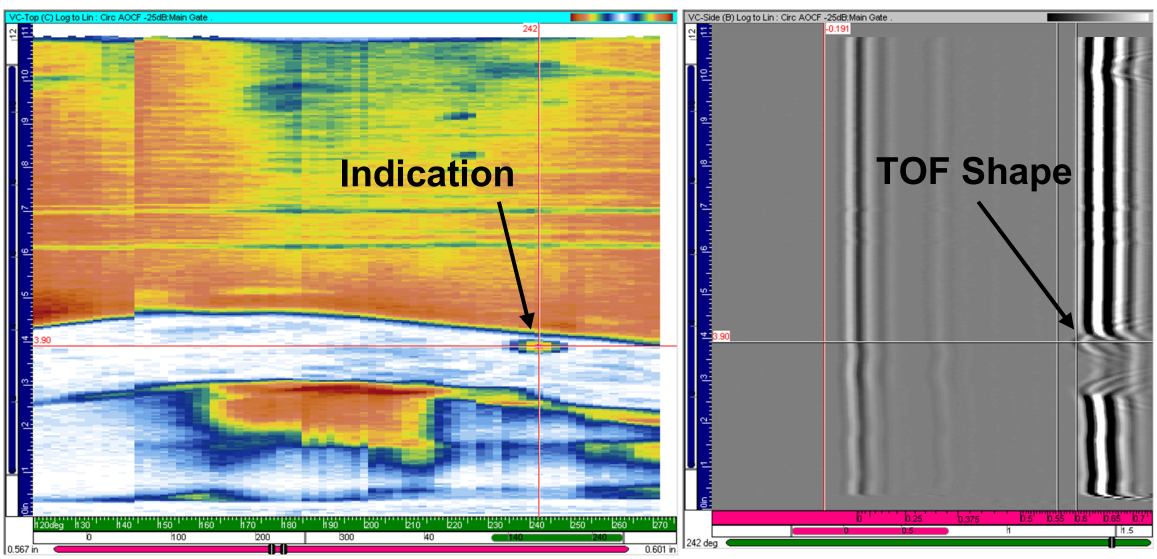

Figure 2.9. AOCF Data Showing Indication at 240 Degrees in Nozzle 12

When the AOCF data is gated around the penetration tube OD, additional TOF-shaped indications were detected in the region ranging from 56–90. These indications are located in the weld, and do not appear to penetrate into the penetration tube.

The COAF and AOCF responses from the OD in the interference fit do not show any evidence of a leakage path in Nozzle 12.

2.3 Nozzle Number 19

When the COAF data is gated around the lateral wave, a series of reduced amplitude axial and circumferential indications appear above and below the J-groove weld region, from approximately 152–225 degrees. A primarily circumferential indication is also seen at 270–18 degrees. These indications are shown in Figure 2.10. None of the indications have a TOF shape. When the AOCF data is gated around the penetration tube ID, the axial indications are clearly detected, and they have TOF-shapes. The AOCF data showing these axial indications are shown in Figure 2.11. These indications are consistent with shallow axial "scratch-like" features, and are not consistent with deep cracks.

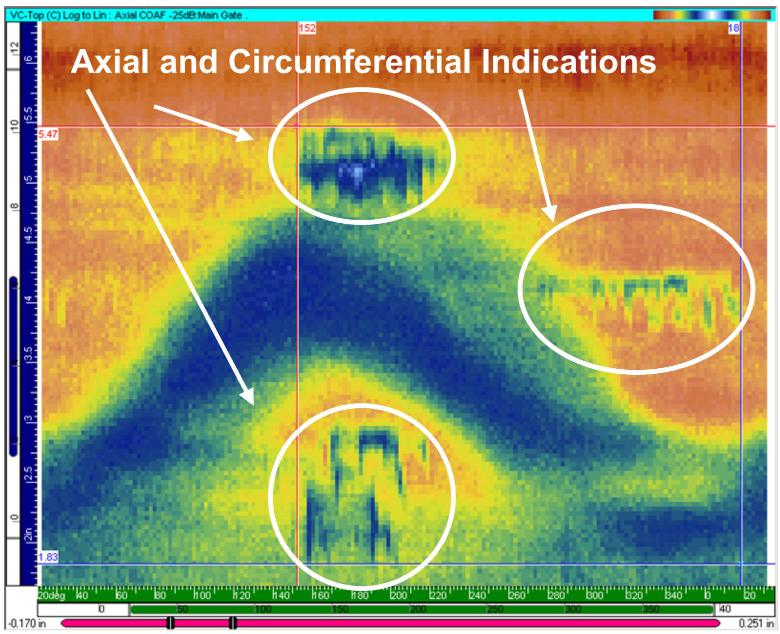

Figure 2.10. Reduced-Amplitude Indications in the COAF Lateral Wave of Nozzle 19

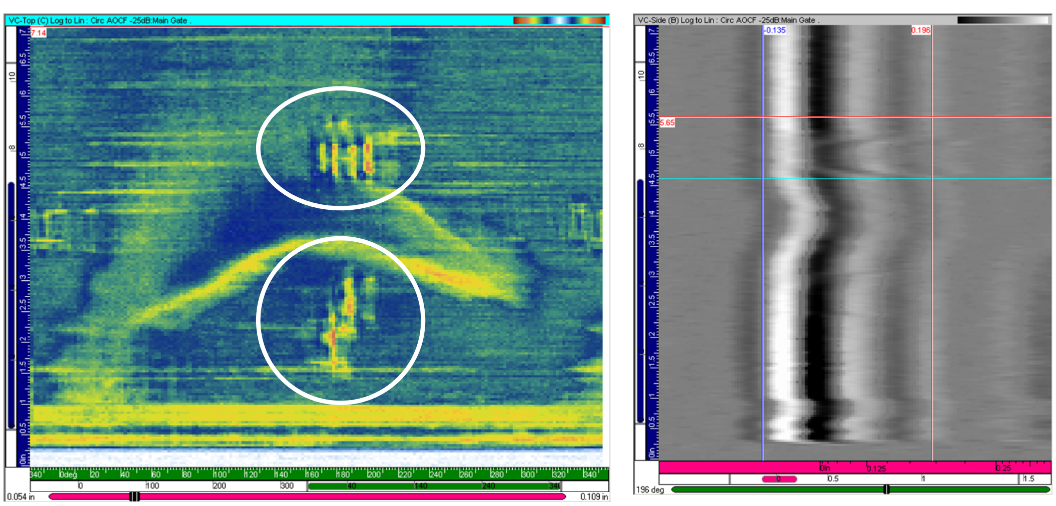

Figure 2.11. AOCF Data Showing TOF Shape Indications in Nozzle 19

When the COAF and AOCF data were gated to examine the center of the penetration tube, no indications or TOF shapes were evident. There were several "X"-shaped responses found in the middle of the penetration tube. It is not known what caused these indications, but they do not have the TOF shape that is associated with cracking and crack tips. An example of the "X"-shaped patterns are shown in Figure 2.12.

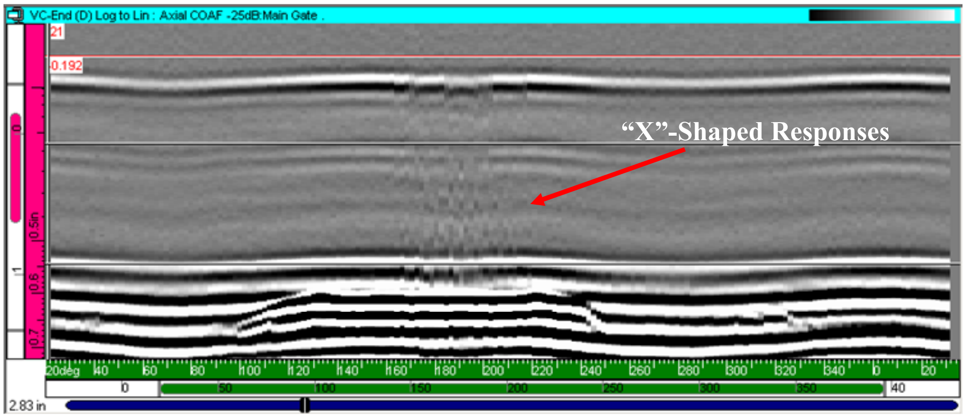

Figure 2.12. Non-TOF-Shaped Responses Found in Nozzle 19

As the data is gated around the penetration tube OD, three areas with indications were found in the J-groove weld region. The strings of responses were found between 4–12 degrees, 166–192 degrees, and 295–339 degrees circumferentially, and are shown in Figure 2.13. These indications have TOF shapes and are shown in Figure 2.14.

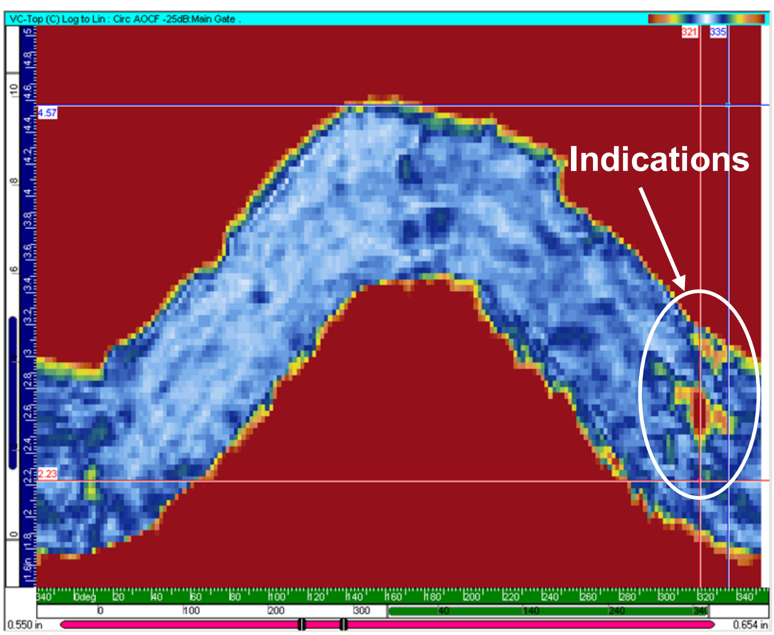

Figure 2.13. Indications Found in the J-groove Weld Region of Nozzle 19

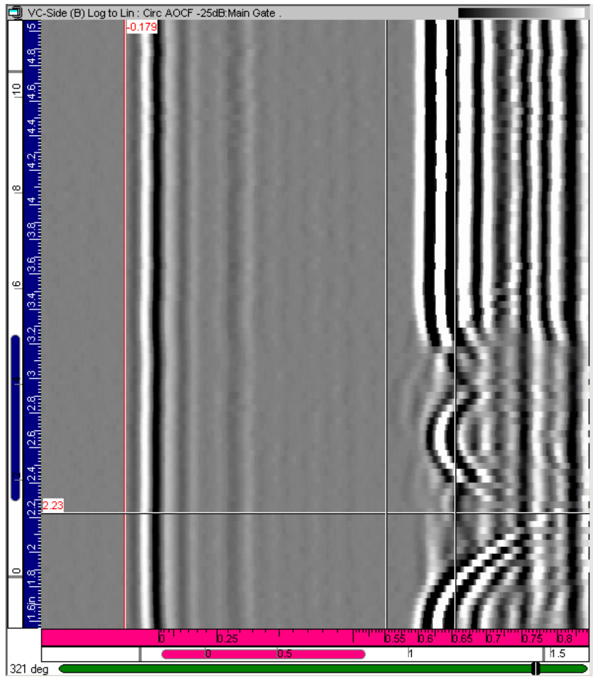

Figure 2.14. AOCF Data Showing Strong TOF Shape Indication in Weld Region of Nozzle 19

The COAF data did not show any pattern associated with a leakage path at the interference fit region. The AOCF data revealed a region of reduced amplitude at the interference fit around 180 degrees, but this region does not exhibit the irregular pattern often associated with a leakage path. This region of reduced amplitude is shown in Figure 2.15.

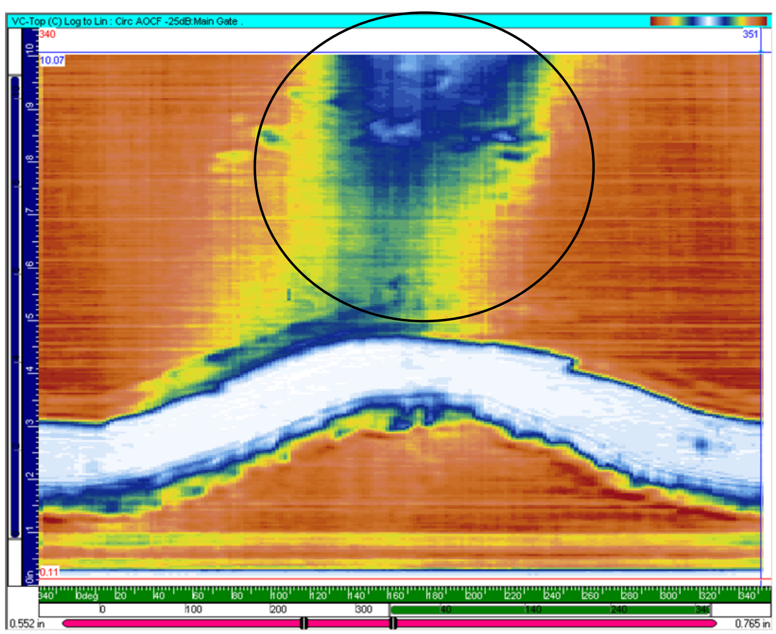

Figure 2.15. AOCF Data Image Showing Reduced Amplitude in the Interference Fit Region of Nozzle 19

2.4 Nozzle Number 40

Analyzing the gated lateral wave region shows no sign of breaks or TOF shapes in either the COAF or the AOCF data. Additionally, there does not appear to be any TOF shapes or indications in either the COAF or AOCF data when the middle region between the ID and OD of the tube is gated. There are no indications of axial cracks.

When the AOCF data is gated to examine the back-wall signal, a shallow indication is found at 177 degrees on the edge of the wetted side of the weld. This welding indication is shown in Figure 2.16. Additional small indications exhibiting TOF shapes were found in the weld region at 90–110 degrees, and 266–38 degrees. These indications are shown Figure 2.17. The intensity of the TOF indications varies over each region. COAF data showed no new indications in this region.

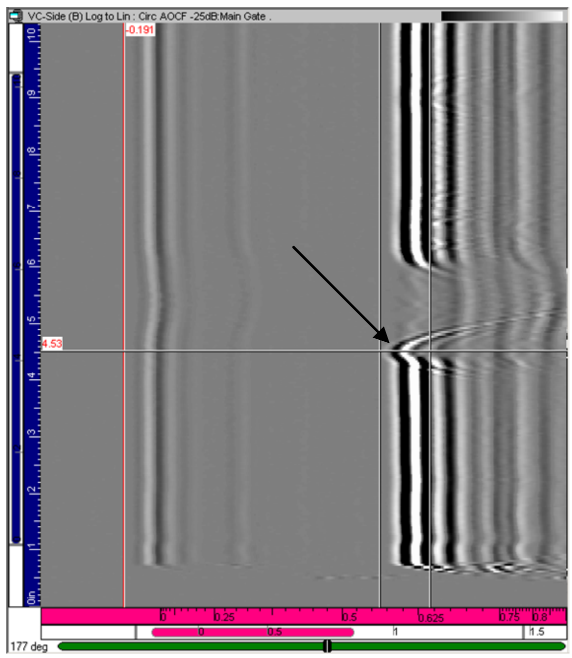

Figure 2.16. Shallow OD Indication in Nozzle 40

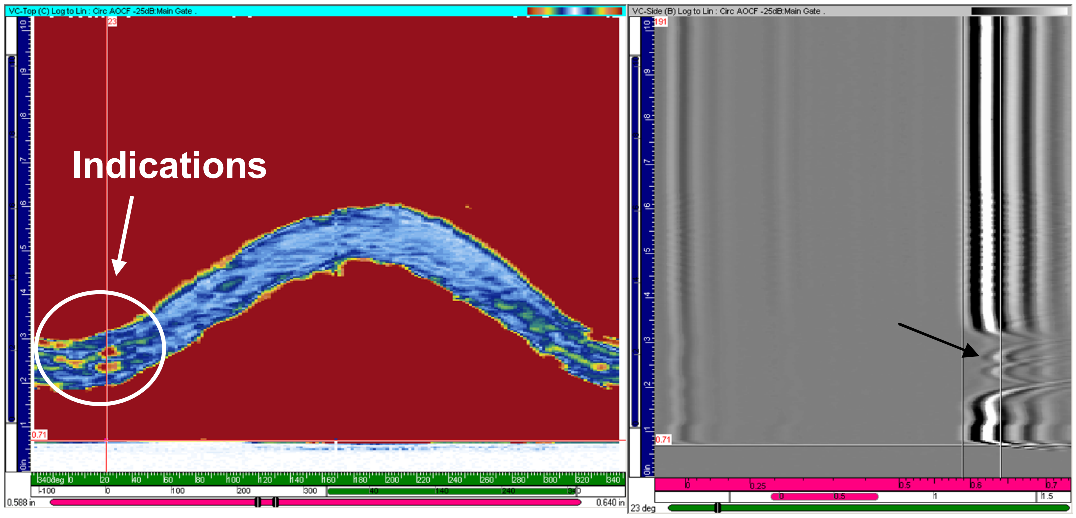

Figure 2.17. AOCF Data Showing a Series of TOF Shape Indications in the Weld Region of Nozzle 40

There is no ultrasonic sign of boric acid deposits in the interference fit of Nozzle 40. The back-wall response is consistent and has no leakage path indication.

2.5 Nozzle Number 42

When the COAF and AOCF data was gated around the lateral wave, no disruptions or TOF indications were found. No TOF-shape indications are seen in the middle section of the tube in the COAF or AOCF data. There are no indications of axial cracks.

When the AOCF data is gated around the penetration tube OD, one finds a string of TOF indications in the weld region. These welding indications are close to the wetted side of the weld and range from 8–40 degrees. These indications are shown in Figure 2.18. Some of these indications seem to penetrate slightly into the tube wall region, and are shown in Figure 2.19.

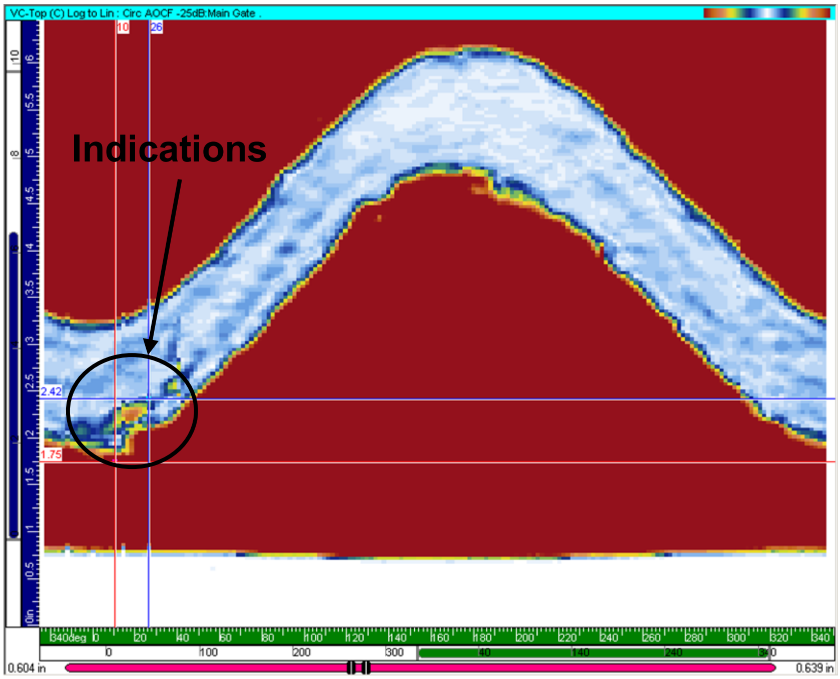

Figure 2.18. AOCF Data Showing Indications in the Weld Region in Nozzle 42

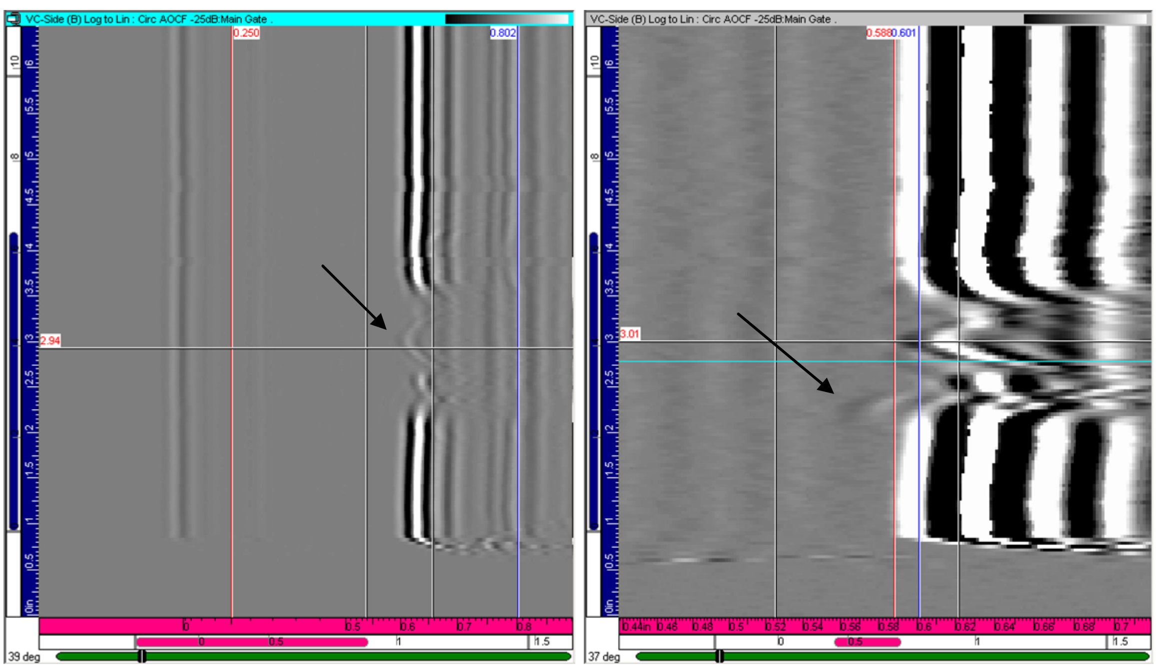

Figure 2.19. Side Views of AOCF Data Showing Possible Penetration into Tube Wall of Nozzle 42

No irregular pattern indicating leakage on the dry side of the J-grove weld was detected in either COAF or AOCF data.

2.6 Nozzle Number 48

When COAF and AOCF data is gated around the penetration tube ID, no TOF or breaks in the lateral wave are visible. The middle region of this penetration tube is free from TOF-shape indications in the COAF data. There are no indications of axial cracks. However, the AOCF data shows a TOF-shape indication at 292 degrees near the OD region on the lower wetted side of the weld to penetrate a short distance into the tube wall, as shown in Figure 2.20.

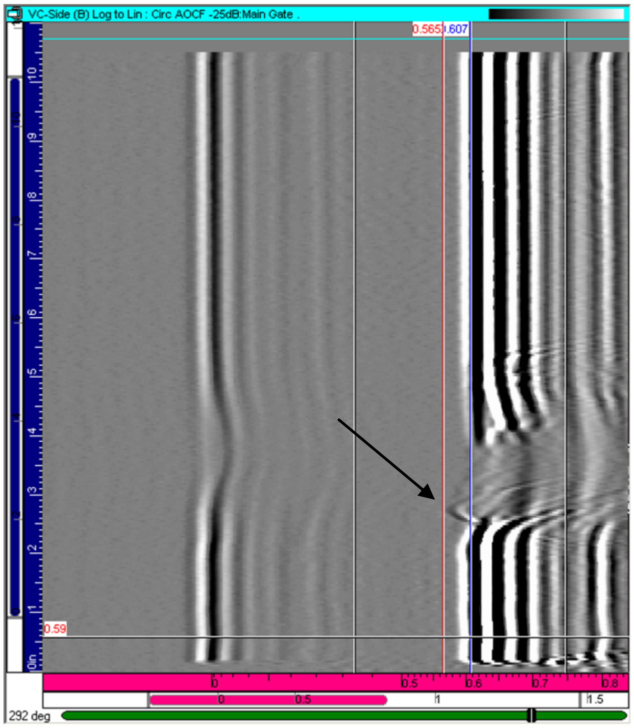

Figure 2.20. Side View of AOCF Data Showing TOF Shape Indication in Lower Middle Region of the Tube of Nozzle 48

When the AOCF data is gated in the OD of the penetration tube, TOF-shaped indications were detected in the weld at 347–52 degrees, 209–215 degrees, and 264–282 degrees. These indications are shown in Figure 2.21, and appear to be embedded in the weld. Indications around 17 degrees show some axial components across a large portion of the J-groove weld region, shown in Figure 2.22. This string of strong reflection responses is also visible in the COAF data. Additional TOF-shape indications were found in the AOCF data on the upper dry side of the weld/butter region at 84–134 degrees and 237–290 degrees. These indications are shown in Figure 2.23.

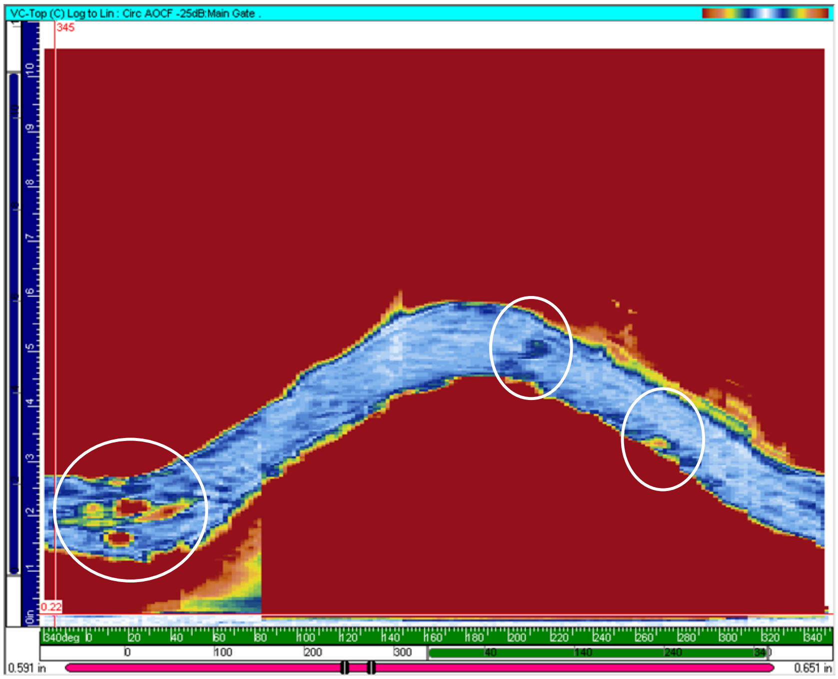

Figure 2.21. AOCF Data Showing Indications in the Weld Region of Nozzle 48

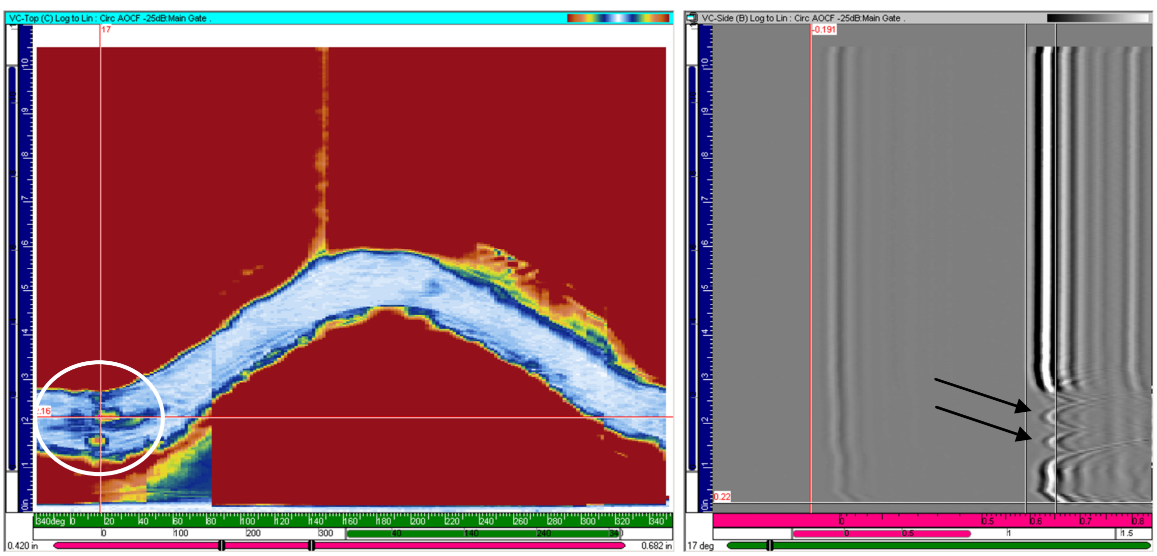

Figure 2.22. AOCF Data Showing Indications Across the Weld Region Around 17 Degrees in Nozzle 48

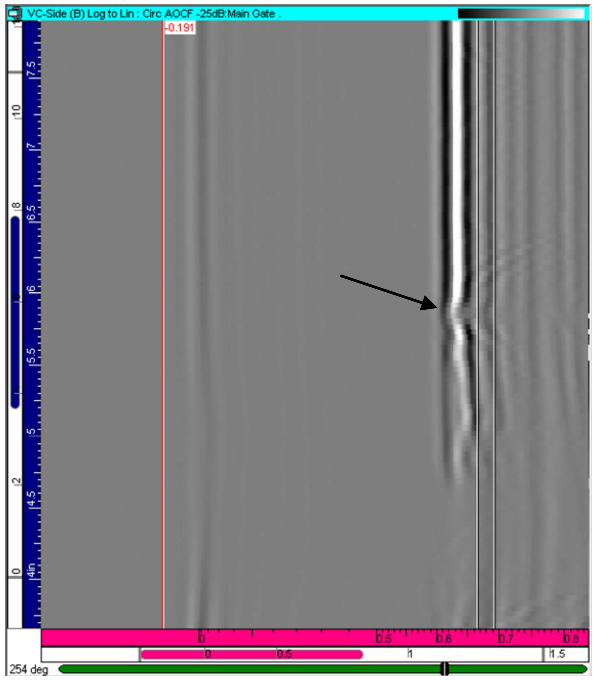

Figure 2.23. Side View of AOCF Data Showing TOF Indications Above Weld Region of Nozzle 48

2.7 Nozzle Number 57

The COAF data gated around the ID show shallow, “scratch-like” indications from 132–219 degrees. The ID indications are shown in Figure 2.24. Another set of indications are located from 320–5 degrees, but these indications appear to be bad scan lines more than anything physical in the material. These indications have an “X”-shaped pattern that crosses the entire depth of the penetration tube. The “X”-shape of the indications is shown in Figure 2.25.

When the COAF data is gated around the back wall, one finds a similar series of non-TOF-shaped axial and circumferential indications from 136–215 degrees and from 3.12–4.31 inches from the bottom of the penetration tube. It is not clear if these patterns are caused by a physical reflector in the tube, as they do not have the characteristic TOF shape.

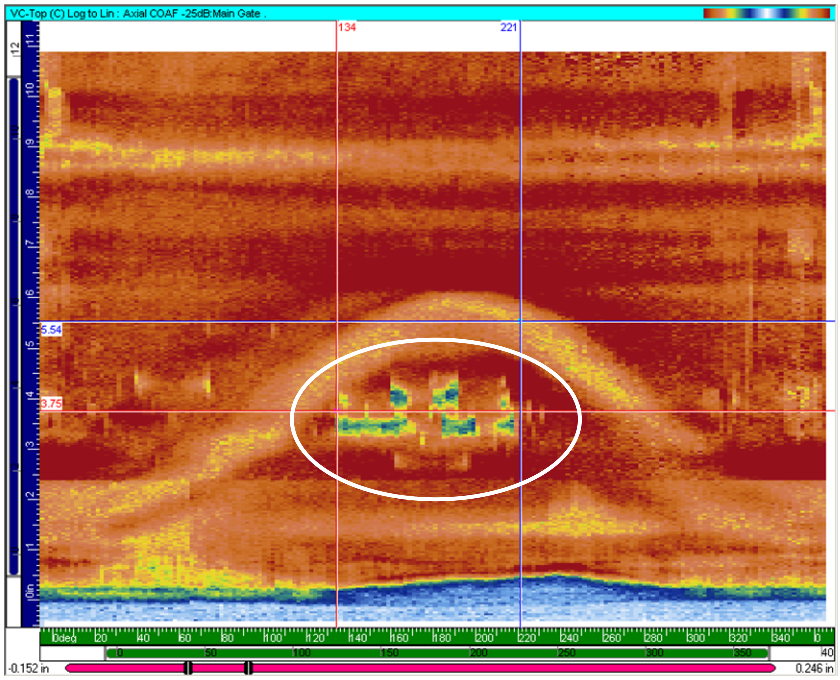

Figure 2.24. ID Indications Found in the Penetration Tube of Nozzle 57

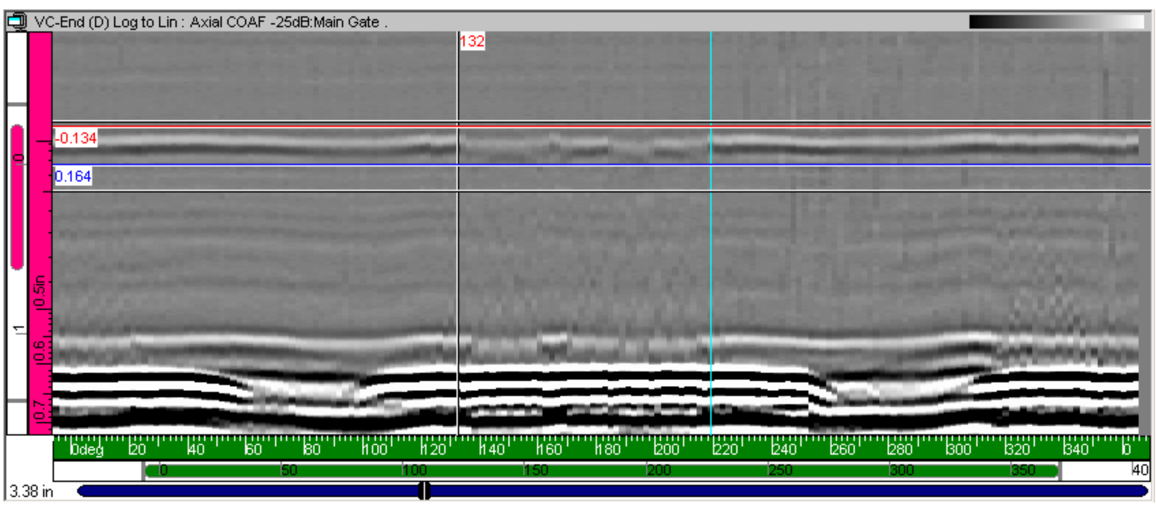

Figure 2.25. "X"-Shaped Indications in the Penetration Tube

The AOCF data gated on the tube ID shows the same indications from 141–209 degrees. The AOCF data shows OD indications at 105–235 degrees above the weld.

When gated near the OD, the AOCF data also contains shallow indications of weld intrusion in the penetration tube near 180 degrees. This is shown in Figure 2.26.

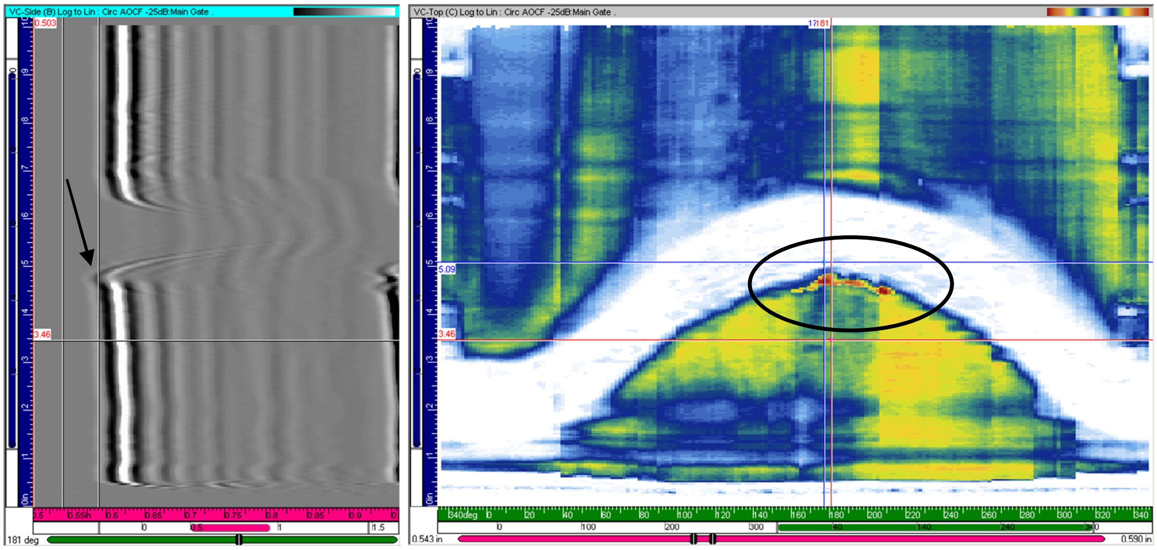

Figure 2.26. Weld Intrusions in Nozzle 57

The back-wall response in the interference fit region shows no signs of a leakage pattern. No irregular regions of transmission or reflection were found.

2.8 Nozzle Number 60

When the COAF data is gated around the ID and in the middle of the penetration tube, no indications are visible. When the COAF data is gated around the OD, a series of weld indications are visible from 18–55 degrees and from 337–343 degrees. These indications are shown in Figure 2.27. An artifact caused by an apparent scanning problem makes an apparent loss of back-wall signal from 25–75 degrees, but this is a function of how one gates the data around the OD of the penetration tube and is not a real effect.

The AOCF data gated on the ID and in the middle of the penetration tube shows no indications. When gated on the OD, the weld indications appear to penetrate into the penetration tube by approximately 0.15 inches. The AOCF indications are shown in Figure 2.28 and TOF shapes indicative of weld intrusion into the penetration tube are shown in Figure 2.29.

There was no sign of a leakage pattern in any of the interference fit data. The response was uniform and did not show the irregular pattern associated with boric acid deposits.

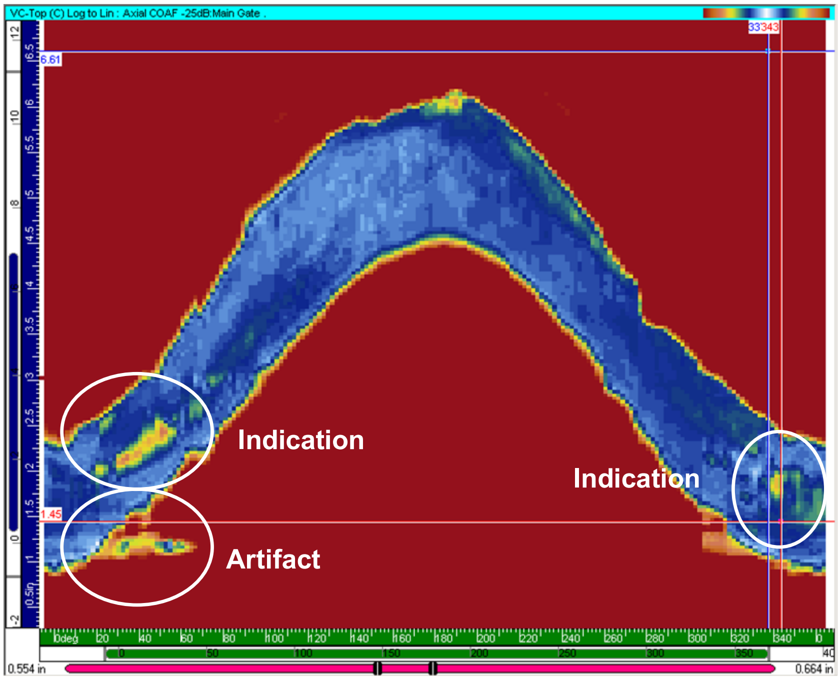

Figure 2.27. Weld Indications in Nozzle 60

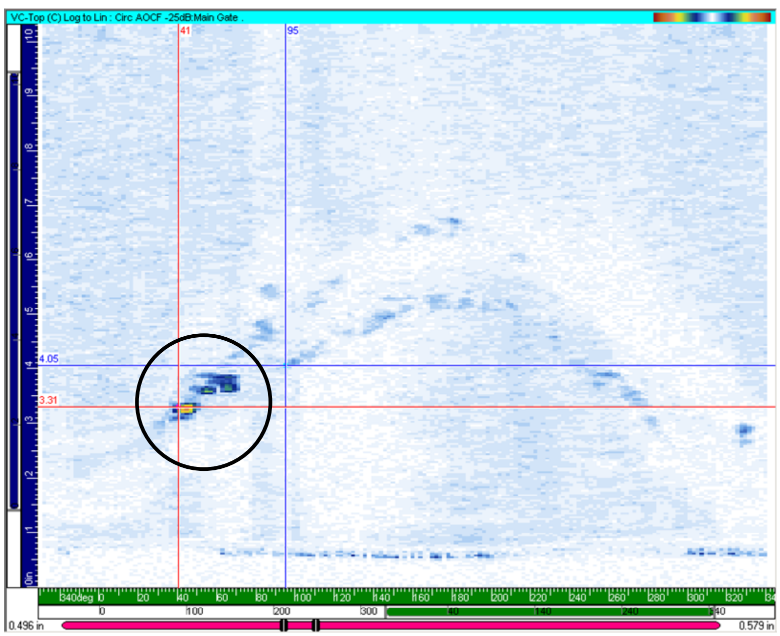

Figure 2.28. Weld Indications in Nozzle 60

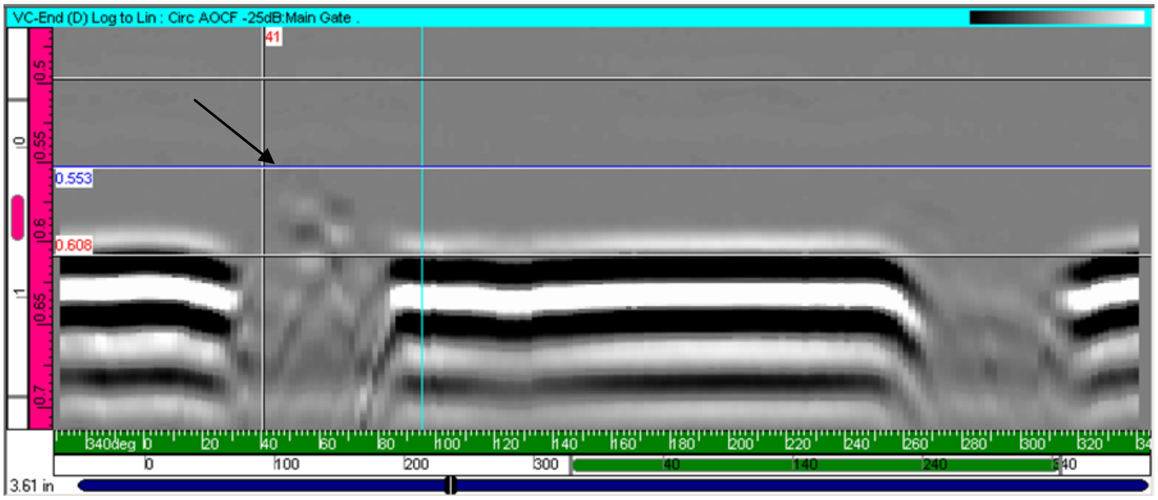

Figure 2.29. TOF Shapes Showing the Weld Intrusion into the Penetration Tube of Nozzle 60

2.9 Nozzle Number 66

When the COAF data is gated around the ID and OD of the penetration tube, no indications were detected. When the COAF data is gated in the middle of the tube, the data show small axial indications with TOF shapes close to the OD of the penetration tube at 101 degrees in the middle of the weld and at 224 and 303 degrees on the dry side of the weld. The locations of these indications are shown in Figure 2.30.

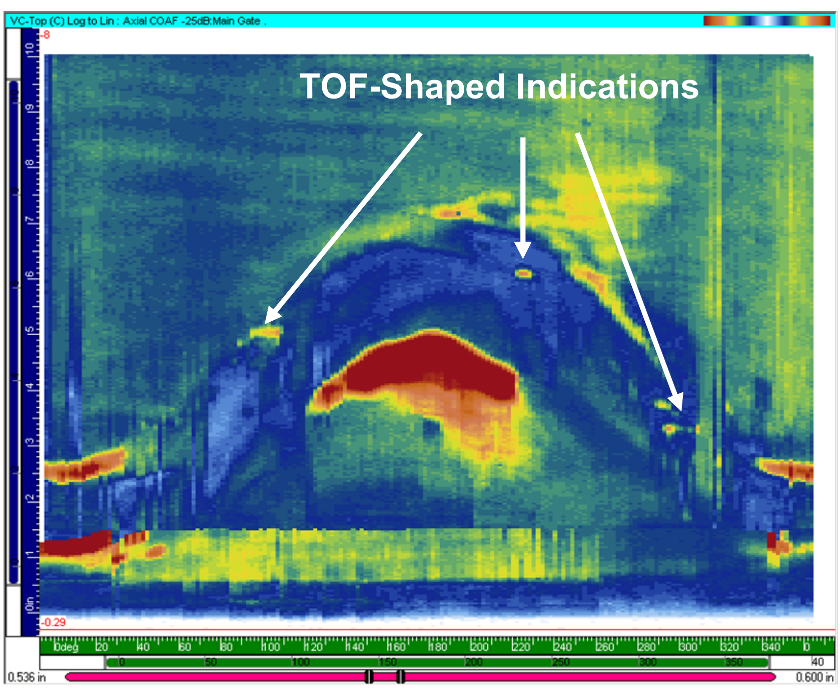

Figure 2.30. COAF Indications with TOF Shapes Found in Nozzle 66

The AOCF data gated in the middle of the penetration tube exhibits these indications and an additional indication at 50 degrees. These indications all fall close to the dry side of the weld and no axial indications appear in the wetted side of the weld. The locations of the high-amplitude weld indications and the weld location are shown in Figure 2.31.

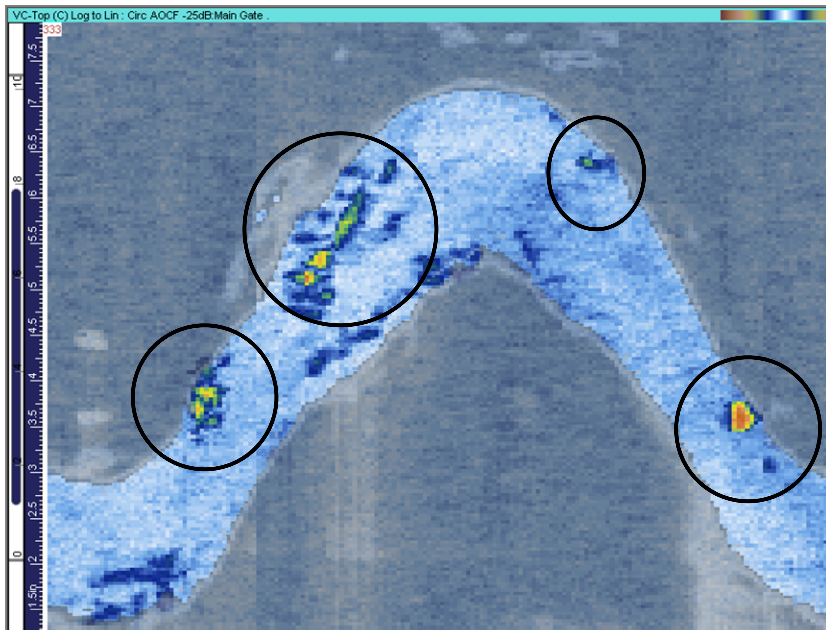

Figure 2.31. AOCF Indications with TOF Shapes Found in Nozzle 66

The indications were generally shallow, with the indication at 50 degrees having a depth of 0.15 inches, the indication at 100 degrees having a depth of 0.1 inches, and the indications at 227 and 294 having depths of approximately 0.05 inches. The TOF shapes are shown in Figure 2.32. It is possible that these indications are caused by a weld intrusion or a weld repair.

A leakage path assessment of the nozzle does not show any clear signs of boric acid deposits. A region of reduced amplitude was found from 104–246 degrees. This region is not large and does not extend more than 2 inches beyond the end of the weld. This region is shown in Figure 2.33.

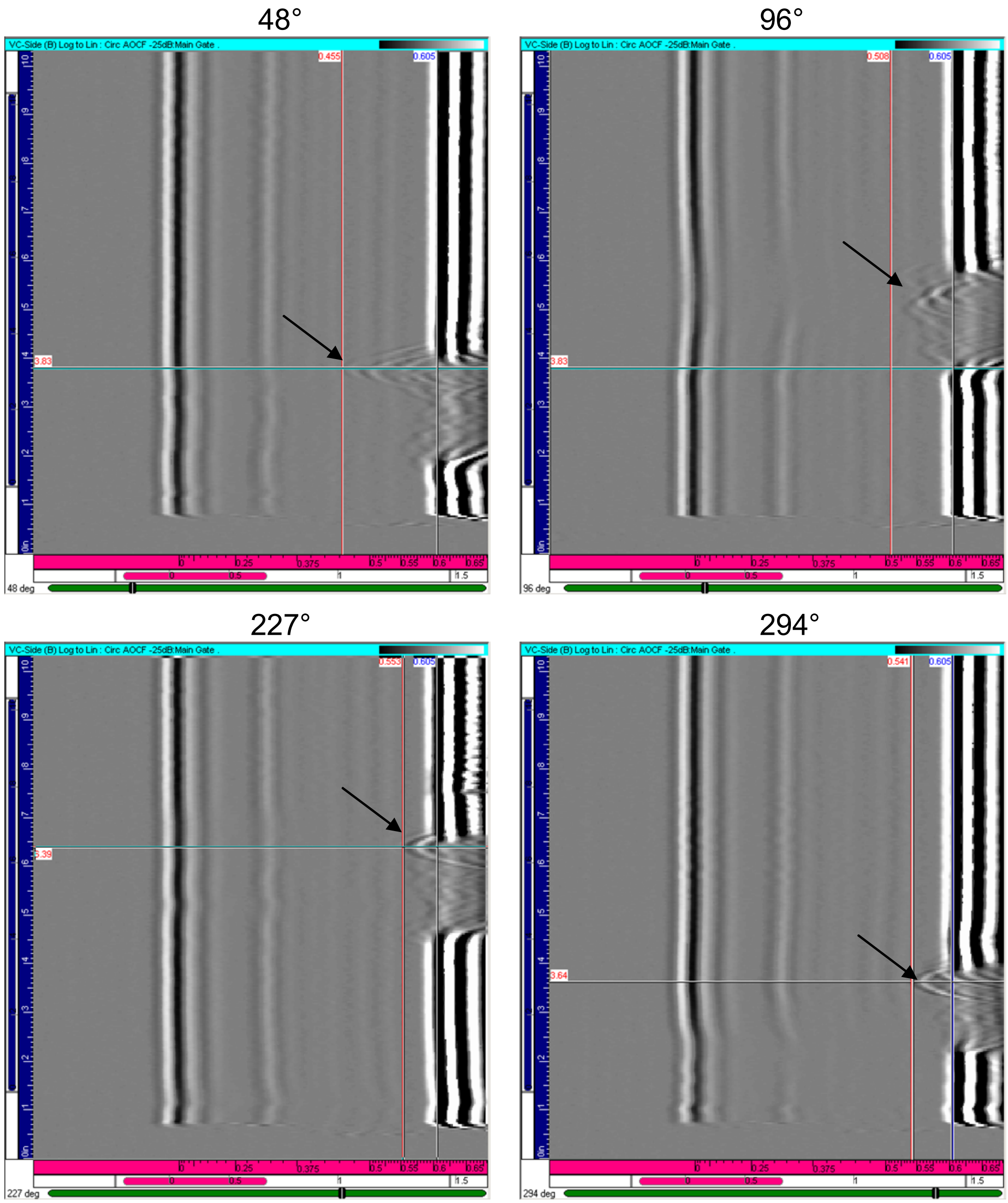

Figure 2.32. TOF Shapes for the Four Indications in Nozzle 66

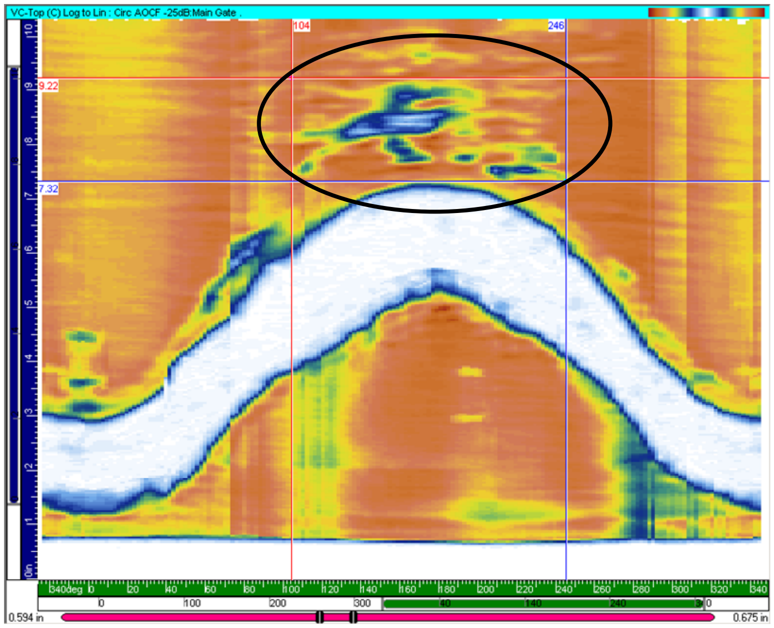

Figure 2.33. Region of Reduced Amplitude in the Interference Fit of Nozzle 66

2.10 Nozzle Number 67

The COAF data found no significant indications when gated at the ID and in the middle of the penetration tube. One small weld defect was detected at 178 degrees when the COAF data was gated at the penetration tube OD. This indication is shown in Figure 2.34.

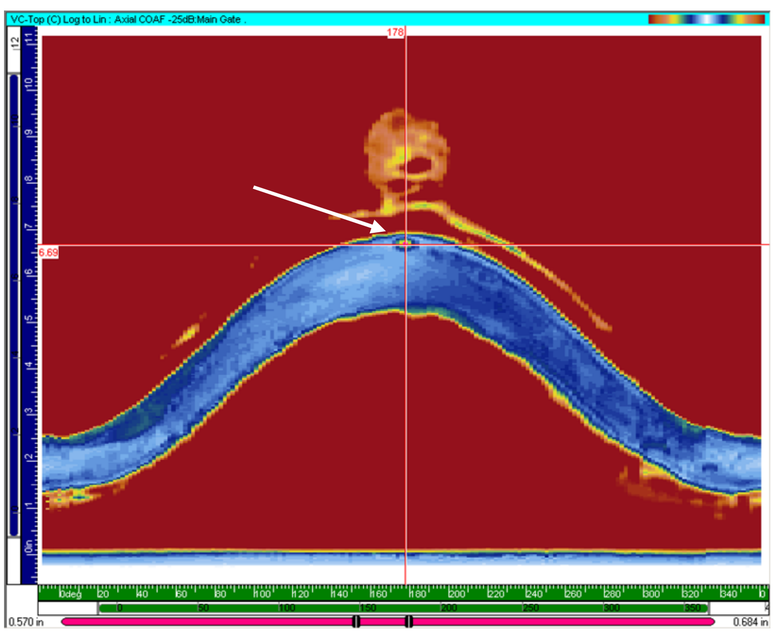

Figure 2.34. Weld Indication in Nozzle 67

The AOCF data does not show any significant indications in the penetration tube. A region of reduced amplitude was found above the weld near 180 degrees. There are many TOF-shaped indications at the tube OD in the region of reduced amplitude. A small indication was visible at 259 degrees that has a depth of 0.05 inches. TOF-shaped indications are present throughout the weld/butter interface on the dry side of the weld. Examples of these TOF shapes and the indication at 259 degrees are shown in Figure 2.35. The region of reduced amplitude is shown in Figure 2.36.

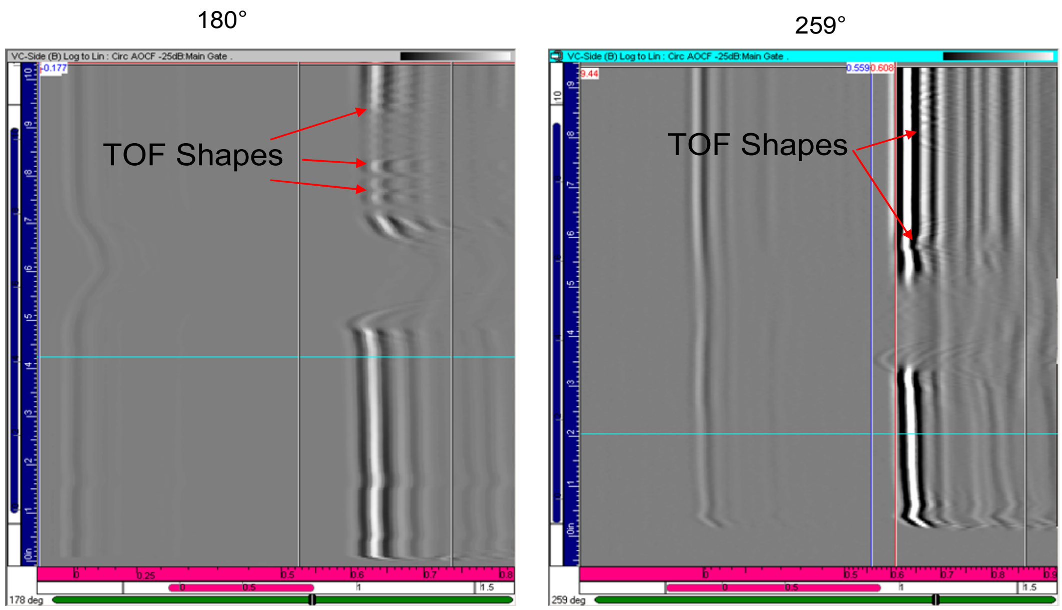

Figure 2.35. TOF Shapes Visible on the OD of the Penetration Tube of Nozzle 67

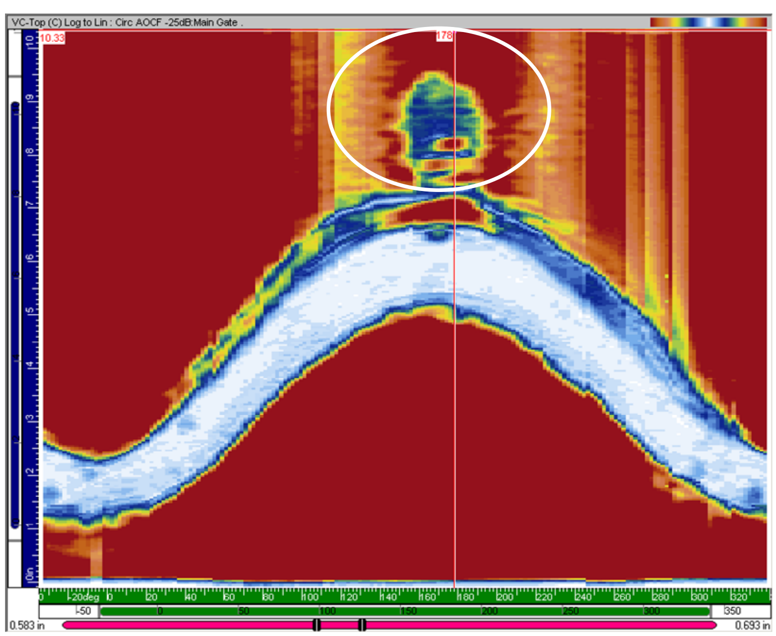

Figure 2.36. Region of Reduced Amplitude Near 180 Degrees

3.0 Summary

After examining the TOFD data in detail, PNNL analysts found indications consistent with cracking in the penetration tube of Nozzle 4 that could have resulted in leakage. Three indications were found, and at least one of the indications crosses the length of the weld, which could provide a path for primary coolant water to enter the interference fit region and leak to the top of the reactor pressure vessel (RPV) head. Additionally, the UT examination of the annulus region shows an irregular pattern of high and low UT transmission that is consistent with boric acid deposits in the annulus.

In nine nozzles (4, 12, 19, 40, 42, 48, 60, 66, and 67), indications consistent with welding flaws, and possible weld repairs, near the weld/penetration tube interface were observed in the TOFD data. Two nozzles, 19 and 57, showed evidence of some form of scanning problem or a surface defect that caused unusual "X"-shaped patterns in the TOFD data. A summary of the PNNL results for the selected ten nozzles is shown in Table 3.1.

Table 3.1. Summary of PNNL Review of Davis Besse TOFD Data

Nozzle	PNNL Findings
4	Three axial indications, one through weld. Possible leakage pattern.
12	Welding indications were found, no axial cracks
19	Shallow axial surface scratch-like indications were found
40	Welding indications were found, no axial cracks
42	Welding indications were found, no axial cracks
48	Welding indications were found, no axial cracks
57	Shallow axial surface scratch-like indications and weld intrusions were found
60	An apparent weld intrusion was found
66	Axial indications found near weld region, weld intrusion, no axial cracks
67	Weld indications and a region that shows reduced amplitude was found

It is worth noting that the TOFD data does not provide sufficient information to make a determination of the state of the J-groove weld; that is, this ultrasonic method does not extend deep enough into the weld region to assess whether PWSCC is occurring within the J-groove weld. The TOFD data is limited to the penetration tube and limited weld region contacting the penetration tube.

4.0 Conclusions

After reviewing the TOFD data, PNNL has developed the following conclusions:

- Indications corresponding to three axial flaws were found in Nozzle 4. One of these indications is believed large enough to result in leakage.
- The ultrasonic leakage path assessment of Nozzle 4 corroborates the flaw indications described above in the previous bullet.
- Nozzles 19 and 57 showed a series of axial indications, but these indications did not have TOF shapes and did not appear to be caused by flaws capable of causing leakage.
- Indications were found in all welds except for Nozzle 57. These indications appeared to be embedded and, thus, fabrication (welding) related, and would not likely result in leakage.
- Nozzle 66 showed what appear to be deep weld intrusions, possibly caused by a repair during fabrication of the J-groove weld.

5.0 References

Cumblidge SE, SR Doctor, GJ Schuster, RV Harris Jr., SL Crawford, RJ Seffens, MB Toloczko and SM Bruemmer. 2009. *Nondestructive and Destructive Examination Studies on Removed-from-Service Control Rod Drive Mechanism Penetrations*. NUREG/CR-6996, PNNL-18372, U.S. Nuclear Regulatory Commission, Washington, D.C.

Key MW. 2010. *Nondestructive Examination Procedure, Automated Ultrasonic Examination of RPV Closure Head Penetrations Containing Thermal Sleeves*. Procedure Number 54-ISI-603-04, AREVA NP, Inc., Bethesda, Maryland.

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