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RESEARCH ARTICLE

EVALUATION OF FLANGE FACE CORROSION USING PHASED ARRAY ULTRASONIC TESTING (PAUT) IN PROCESS INDUSTRY

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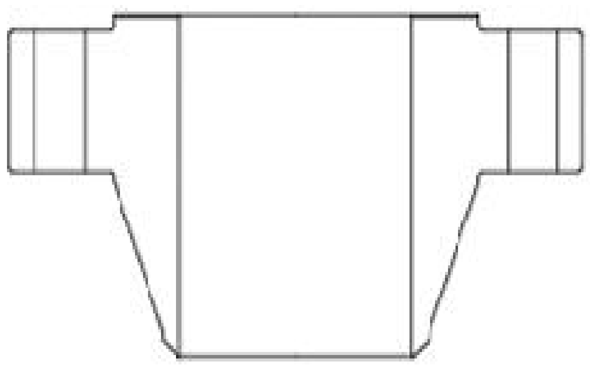
ABSTRACT

Crevice corrosion [3] is a well-known damage mechanism in Oil and Gas facilities and is caused by a concentration of corrosive substances within a confined space. The crevice between two adjoining flanges is the ideal environment for initiation of crevice corrosion. Because of the concentration of these corrosive substances in a localized area, rate of corrosion gets accelerated. When flanges are used in very corrosive environments such as sea water, acid service and H2S concentrated drain piping the flange face is particularly susceptible. Corrosion of the sealing area can cause loss of containment and therefore have the potential to cause a release of product with potentially catastrophic consequence. Phased Array Ultrasonic testing technology [6], was recently introduced by specialized inspection companies, the technology can be used to identify the flange face gasket seating surface condition and extent of corrosion in all types of Carbon Steel flanges (weld neck raised face and ring groove) in the Piping and Pressure vessels while in service and without the need to separate the flange joint. The PAUT technology can be described as a semi-quantitative technique to measure the metal wastage (Crevice corrosion, erosion etc.,) at the flange faces gasket seating area. Defect dimensions are measured in C-Scan image (plan view) and POD [2] (Probability of detection) is up to 90%. The PAUT technology was validated in the current research by two ways one is by break opening few bolted in-service flanges and also by the use of flanges with artificial defects/flaws and compare them with inspection findings. This research paper is discussing the results for the use of PAUT technology in a large scale inspection survey of the process industries. The paper will discuss results, results validation, technology strength point and limitations. The same is seen as valuable information for all oil and gas operators worldwide.

INTRODUCTION

The in-service inspection of flanged joints is a considerable issue for the on-going integrity of hydrocarbon processing facilities. A flanged joint consists of two mating flanges with a sealing mechanism (gasket or O-ring) between them. These joints are a break in the continuity of a line and present a route for loss of containment in the form of leakage. Loss of containment in hydrocarbon, high pressure gas or high pressure water systems is a significant safety issue and effective inspection strategies are essential to ensure the integrity of the joints at all time. There are two flange types commonly used on plant; Welded Neck (WN) Raised Face and Welded Neck (WN) Ring type joints (RTJ"s) and these are shown in the figure below. This paper is solely concerned with raised face flanges:



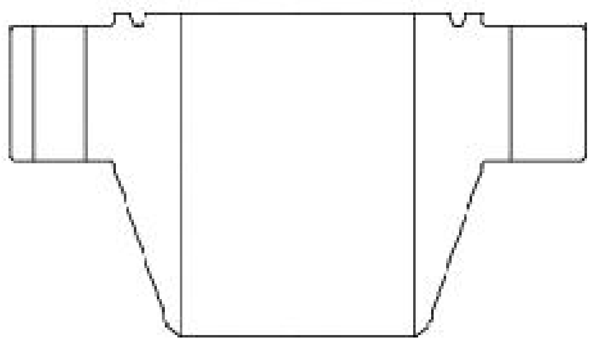


Figure 1. Example of the two most commonly found flange joint. Raised face (left) and Ring type joint (right)

The crevice created on the inside diameter of a flanged joint presents an inherent location for localized corrosion to occur. [4] Carbon steel flanges are particularly susceptible to such attack. Over time, the corrosion of the flange face may extend into the gasket mating area potentially compromising the seal integrity of the flanged joint. Several factors can influence the rate at which the flange face may corrode. The inspection frequency of flanged joints should consider the respective corrosion rate in conjunction with the calculated sealing surface requirements. The collections of corrosive materials [3] concentrate between the crevice of the sealing surface and gasket material (see Figure 2). This damage mechanism is of particular concern for flanges used in highly corrosive environments such as

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Hydrofluoric Acid (HF) transportation, Hydrocarbon with high % of H2S and sea water service which is an integral system in an oil refinery/process plant. Because of this concentration in a localised area the rate of corrosion is accelerated. Corrosion of the sealing area can cause loss of containment and therefore have the potential to cause release of product having catastrophic effect.

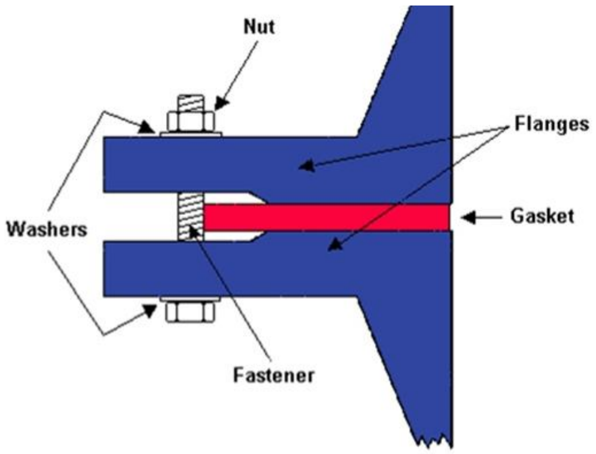


Figure 2. Welded Neck Raised Face Flange showing gasket seal

The current philosophy for inspection of flanged joints is the periodic breaking of the joint and visual inspection of the sealing faces of the joints. The disassembling of flange joints is both time consuming and involves the shut down and de-inventorying of the system. This is costly and can introduce other corrosion risks by allowing air ingress into systems that do not normally see oxygen. Attempts have been made to introduce a non-intrusive inspection method in order to reduce costly shutdowns, but unfortunately due to the complexity of the joint no reliable method has been identified. Initial methodologies were based predominantly on conventional A-scan ultrasound. Being limited to mono-angular inspection and subjective analysis, attempts to introduce the method did not develop.

It has therefore become a requirement to improve upon current inspection methods and the introduction of phased array technology [6] into the industrial environment has provided the means for such improvements. Phased Array has the ability to simultaneously collect A-scan data at a number of given angles [5].

This unique feature produces a volumetric beam allowing operators to distinguish between geometric reflectors and defect signals and therefore increasing the likelihood of detection. In addition, this ability also improves flexibility on complex geometries as the beam can be controlled to suit the requirements of the inspection. Conventional methods of ultrasound inspection are based on fixed angle probes which can be severely restrictive when inspecting parts with unfavourably orientated discontinuities.

As previously discussed flange joints are commonly categorised into two main forms; Raised Face (RF) and Ring Type Joints (RTJ‟s). Although similar in their external appearance, the sealing face for each differs considerably and therefore requires individual attention with regard to technique design.

The Raised Face Flange is the most commonly used of all flange faces in low pressure systems. The flange has a raised area machined on the flange face equal to the contact area of a gasket. The part of a flange where the gasket touches is called the contact surface. This area is the most critical area to the prevention of leaks. Flange faces are machined with standard finishes. The most common finish for the contact face of a flange is a concentric groove. This pattern is machined into the flange face and provides the grip for the gasket. It is referred to as a raised face because the gasket surfaces are raised above the bolting circle face.

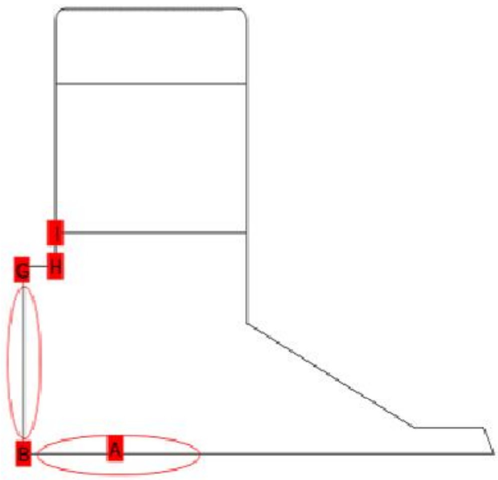


Figure 4. The internals of a raised face flange can be described as three connected zones

Flange Bore

This area of the flange is the internal diameter of the flange and is the flow path for fluid through the flange (Position A Figure 4). The corrosion mechanisms for the flange bore are largely the same as those for the pipe that the flange is connected to and wall thickness at the bore is equal to or greater than that of the pipe when the taper of the flange fitting is taken into consideration. Two additional damage mechanisms for the bore are galvanic corrosion which can occur if there is a mismatch in the material or the pipe and the flange or preferential weld corrosion and erosion or turbulent flow regimes. General corrosion detected on the flange bore should be viewed in the same light as internal corrosion of the surrounding pipe with the key variable being minimum thickness.

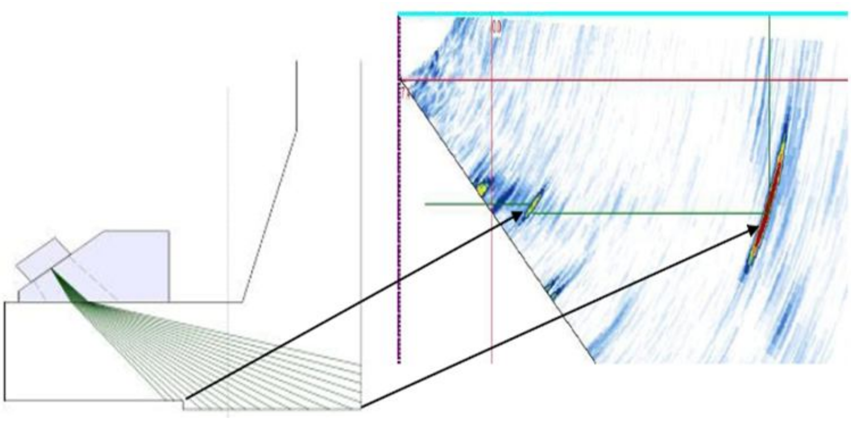


Figure 3. Showing a phased Array image generated from a defect free flange

The corner edge of a flange is the transition from the bore of the pipe to the sealing surface of the flange itself (Position B Figure 4). Typically, in a raised face flange, the gasket which acts as a seal covers the area of the raised face from the corner edge to the end of the machined surface of the raised face. As such the corner edge is the start of the sealing face but edge corrosion is not an immediate threat to the integrity of the flange seal. Loss of the edge can create a crevice that allows for enhanced corrosion but as long as this is held at the edge position it does not pose a leak or integrity threat to the system beyond that experienced by the pipe itself.

Raised Sealing Face

The sealing face of the flange is the machined face that extends from the corner edge of the flange to the outer radius of the machined face. This area is covered by the area of the sealing gasket (Element B to G Figure 4). Corrosion damage of the sealing face is the critical factor in the integrity of the flange.

REQUIRED INSPECTION ZONE

The inspection zone is defined as the raised face area (where the gasket sits) and a proportion of the internal bore. Figure 5 below illustrates the focal laws used (left) and the typical response from a non-defective part (right). Note the geometric response from the bore to face corner. In order to gain maximum coverage and thus improve defect detectability, the inspection developed has incorporated three individual scan positions and includes both encoded data and manual scanning [2].

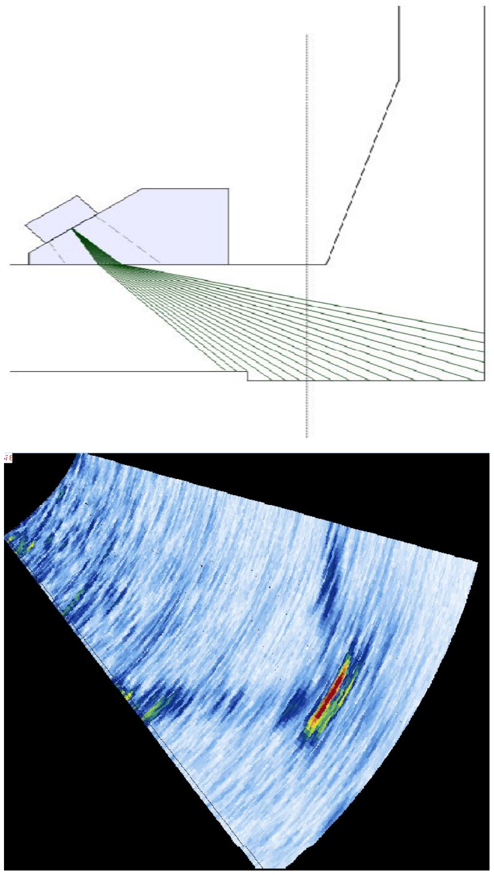


Figure 5: Inspection coverage

The Phased Array technique developed within this project uses a combination of manual [1] (not automated) and encoded inspection. The scan positions are between the bolt holes (Scan 1) and from the flange taper (Scan 2). Scan 1 is a manual technique, whereas scan 2 can utilise a wheel encoder to collect electronically stored data.

Scan Positions – Position 1:

Due to the geometry of the flange components the location between the bolt holes (scan position 1) is square to the flange face and therefore the most reliable inspection for corrosion detection. This is because any loss of material will severely affect amplitude of the corner reflector. Probe placement is of particular importance for Scan 1. Each placement requires the probe to be skewed from -30 – 30 degrees (this skew maybe restricted depending on bolt hole spacing).

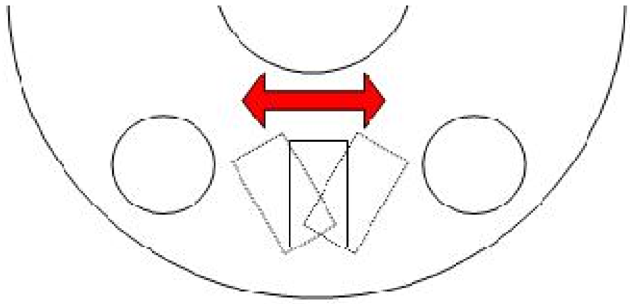


Figure 6: Probe skew requirements

This inspection is run through Tomoview software in Inspection mode. By using engineering drawings as software overlays, operators can position probes to locate geometric reflectors helping to identify any abnormalities [6]. The image in Figure 7 shows screen grabs from Tomoview Inspection.

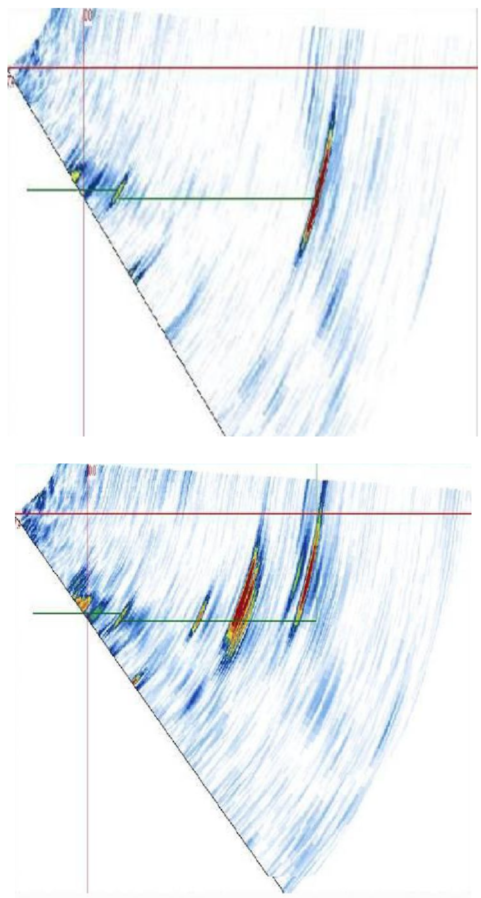


Figure 7: Use of engineering overlays

The image on the left shows no flaws with geometric reflections [5] from the face to bore corner and tip diffraction signals from the raised faced corner. The image on the right shows typical responses from areas of corrosion. Note the complete loss of corner reflector.

The flange faces of Mock-up samples were inspected and 13 flange faces of in-service joints were visually tested. See detailed observation in Table 1. The following in service flanges were identified to have significant deterioration. In-service flange – 2 (6" NB) In-service flange – 7 (10" NB) Validation Exercise

Item No.	Identification	Flange ID	Phased Array	Validation	Remarks
			Mock up Sample Flanges		
1	6" Flange Mock-up sample.	Two Flanges	Actual defects identified by PA Locations marked on specimen	Validated. 4 out 4 defects identifiedby PA	None See Photographs 1-4 PAUT Image 1- 2
2	10" Flange Mock-up sample	Two Flanges	Actual defects locations corresponded to PA Identification marks on specimen	Validated 5 out 5 defects identified by PA	None See Photographs 5-6 PAUT Image 3- 4
			In-Service Flanges		
3	In service flange-1	Top (A)	15mm x 5 deep	No deterioration noted	Corner reflector from the cement lining eroded locations.
		Bottom (A)	NRI	No deterioration noted	None Photograph 7-8
4	In service flange-2	Bottom side	Severe corrosion at corner and in sealing edge- Reject	Deterioration noted	See Photograph 10
5	In service flange-3 and 4	Top (A)	Isolated pit -Acceptable	Deterioration noted	Minor pit noted PAUT Image - 5
		Bottom (A)	NRI	No deterioration noted	None
		Top (B)	NRI	No deterioration noted	None
		Bottom (B)	NRI	No deterioration noted	None
6	In service flange-5 and 6	Top (A)	NRI	No deterioration noted	None
		Bottom (A)	NRI	No deterioration noted	None
		Top (B)	NRI	No deterioration noted	None
		Bottom (B)	NRI	No deterioration noted	None
7	In service flange-7	Top Bottom	20 x 12 deep Reject – intermittent corner loss full circle – worst area noted	Deterioration noted	Severe wastage noted at inner edge. See photograph11 PAUT Image – 6-7
			NRI	No deterioration noted	None See photograph 12

Table 1. Validation of Mock up flange and In-service flange using PAUT PA –Phase Array NRI- No Recordable Indications

Scan Positions – Position 2:

Scan 2 collects information from the tapered neck area of the flange face. This scan can use a wheel encoder to help interrogate the flange face to bore corner area. By collecting encoded data operators can use an unmerged B-scan, to help identify changes in beam path resulting from material losses. Image below (Figure 8) show inspection set-up and how an unmerged B-scan can be utilised

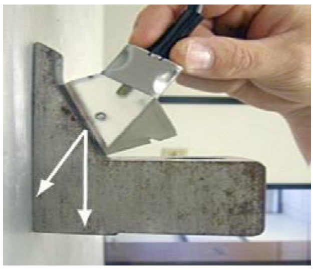


Figure 8: Probe placement

6"Mock-Up Flange Defect locations & length marked on the external surfaces of pipe correspond to actual depends when flanges were dismantled

Photo. No.1

Photo. No.2

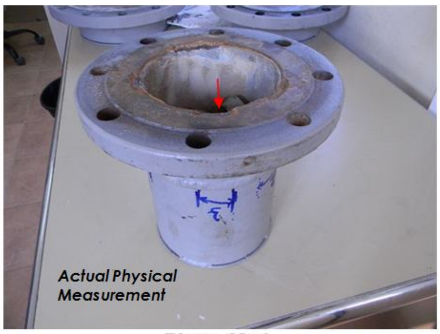


Photo. No.3

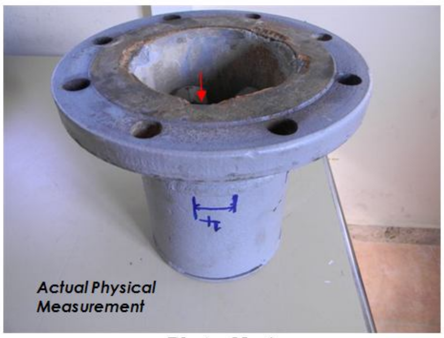


Photo. No.4

10" Mock-Up Flange

Defect locations & length marked on the external cover of pipe correspond to actual depends when flanges were dismantled.

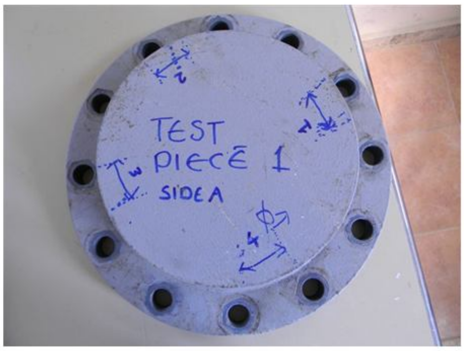


Photo. No.5

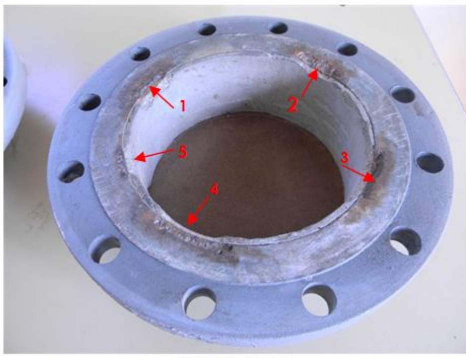


Photo. No.6

In-service flange-1 No significant deterioration noted during physical inspecton as reported by Phased Arrays

Photo. No.7

Photo. No.8

In-service flange-2 Corrosion wastage on inner edge of gasket face reported by Phase Array was verified when the NRV cover was opened

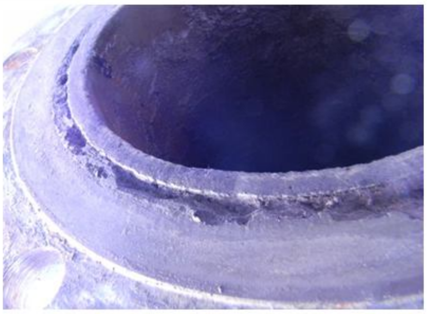


Photo. No.9

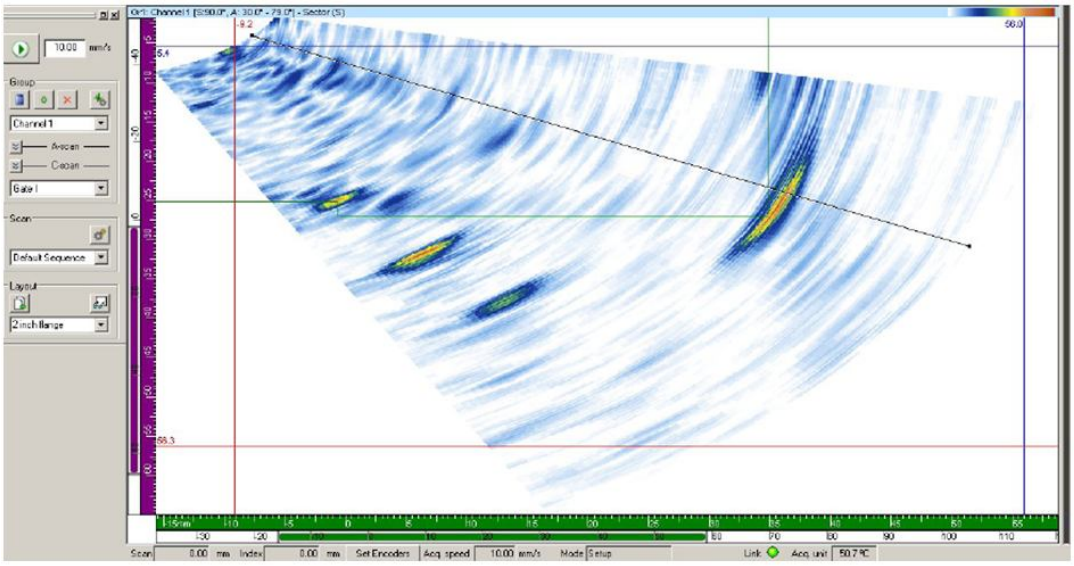
Photo. No.10

In-service flange-7 Deep Corrosion wastage on inner edge of gasket face reported by Phased Array was verified when flangejoint was dismantled and inspected. Severe wastage of approx. 16 x 12 deep on flange face at flange/cement lining interface.

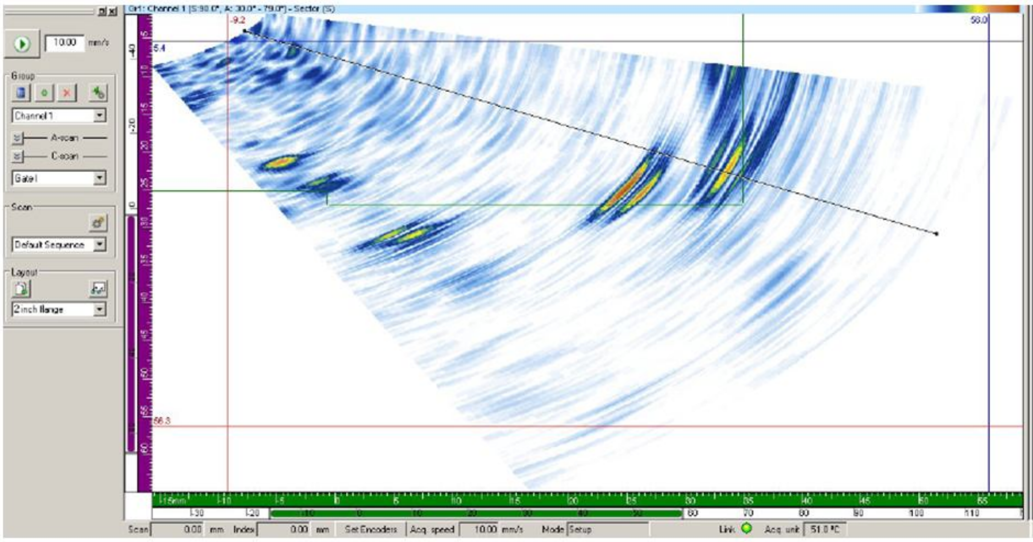
Photo. No.11

Photo. No.12

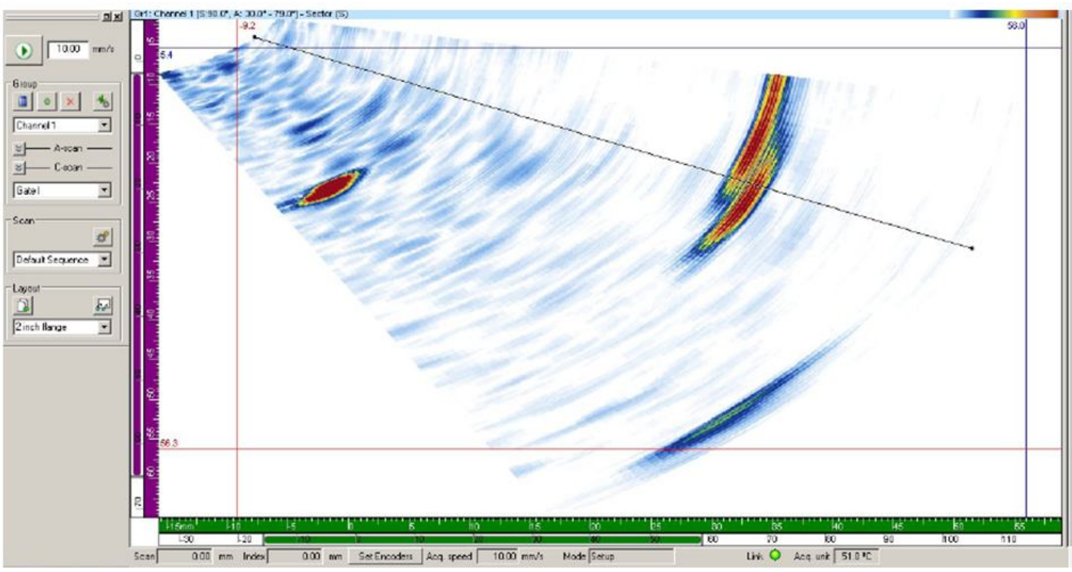
TYPICAL PAUT SCAN IMAGES



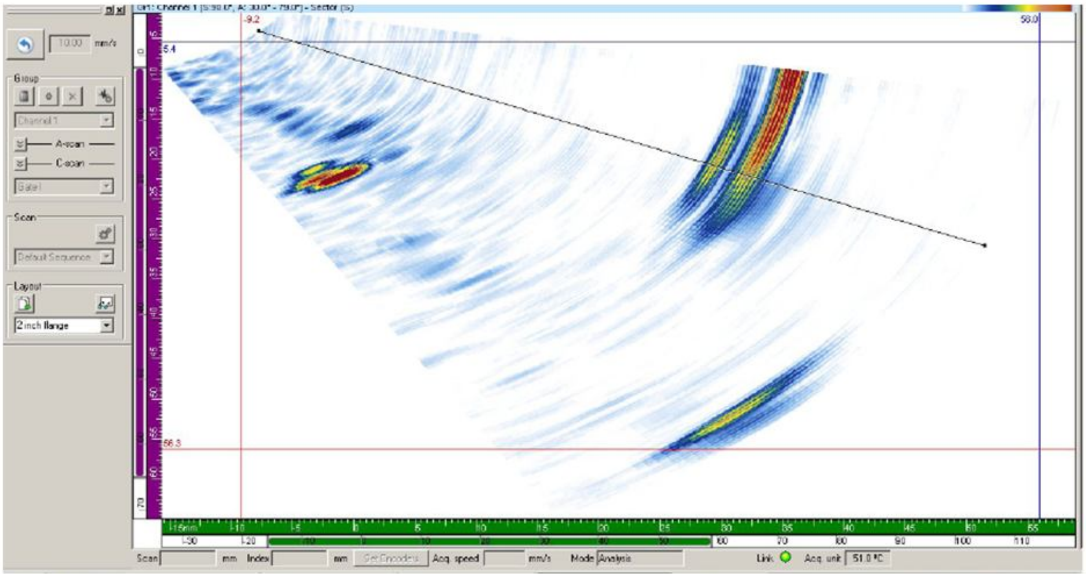
Good area – Mock-up Flange 1-Image 1



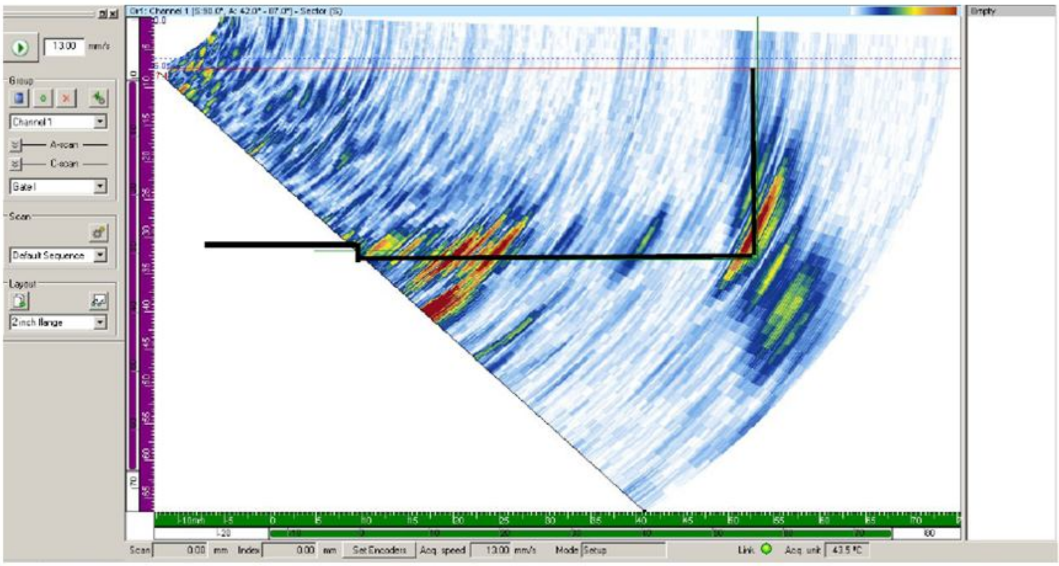
Area of damage – Mock-up Flange 1- Image 2



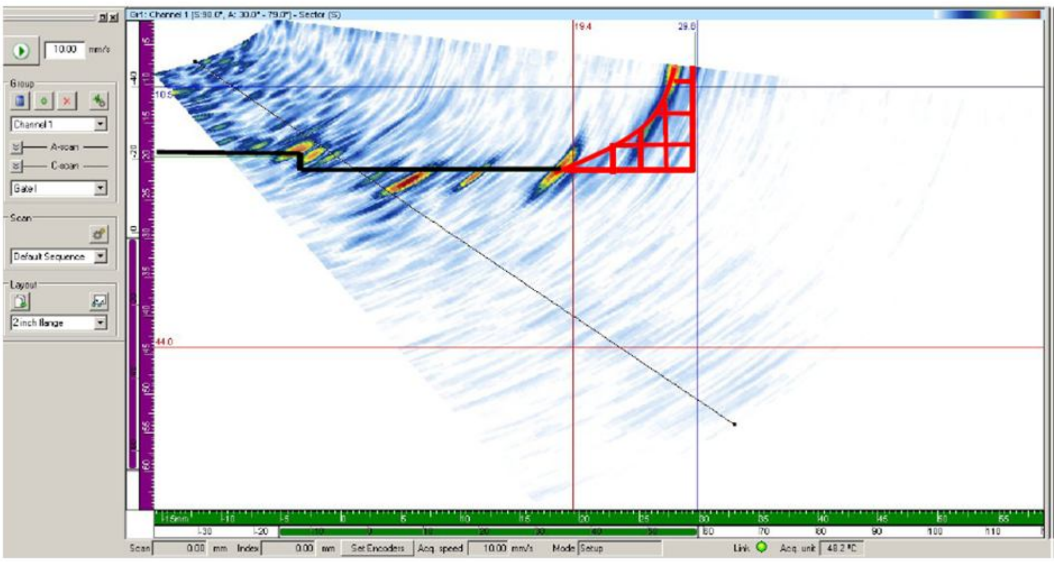
Area of damage – Mock-up Flange 1- Image 3



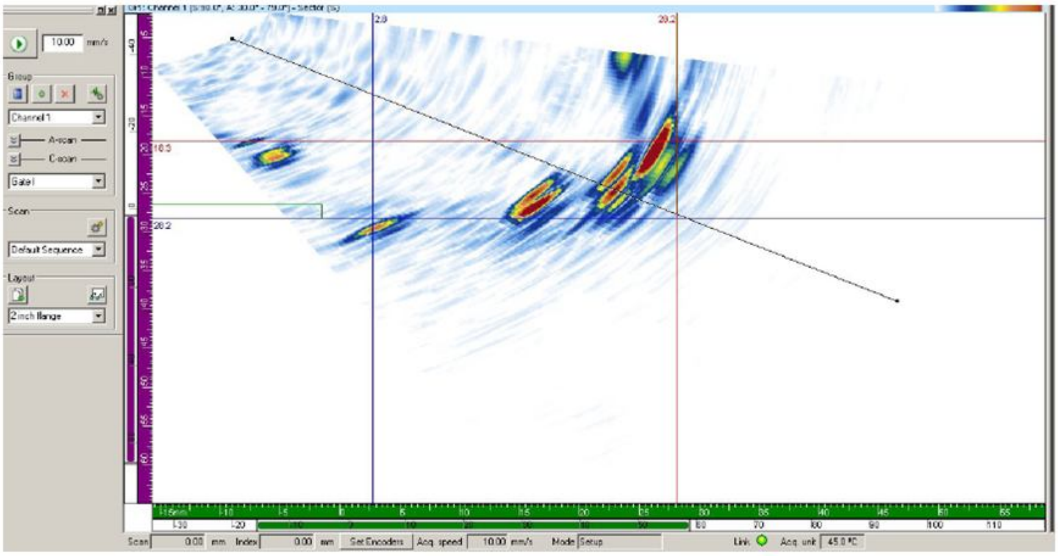
Area of damage – Mock-up Flange 1- Image 4



Area of damage – Isolated pit-In-service flange 1- Image 5



Area of damage – deep corrosion -In-service flange 1- Image 6



Area of damage – deep corrosion -In-service flange 1- Image 7

VALIDATION EXERCISE

A Phased array test exercise was performed using 02 nos. (6"and 10" dia Carbon Steel-A105) mock-up test flange joints with built in defects were tested. Further, in total of 100 in-service flanges were also tested using the PAUT method.

Conclusions

All Phased Array inspection findings were visually confirmed with a physical examination. Considering the level of validation, this is a significantly a promising result. Therefore, it can be concluded that Phased Array is a reliable method for the detection and sizing of in-service corrosion damage, located on the sealing face of raised face flanges.

Acknowledgement

The author wish to thank Dr. Pravina Pinto – Engineering Consultant and Dr. Ashutosh Panday-Associate Professor-UPES-Dehradun for extending the necessary support and guidance in order to carry out the Phased Ultrasonic Testing Validation exercise to identify the in-service flange face corrosion in the process industry.

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