Single Sided Weld Inspection using Advanced Ultrasonic Methods

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Abstract:
Advanced ultrasonic examination methods such as Phased Array Ultrasonic Testing (PAUT) & Time of Flight Diffraction (ToFD) have been an effective volumetric examination for welds. This is true for access of scanning from both sides, however for single side access welds, such as welds at elbow, flange and cross-section pipes, the limited scanning compromises the detection of lack of fusion on the bevel opposite to the probe side. Single sided access weld examination in conventional approach using phased array is dependent on back diffraction signals with increased dB levels. However, it is difficult to achieve higher confidence level of detectability for such flaws. This paper provides a case study on single sided examination using inspection simulation software and confirms the same using practical testing on specimens. This case study also compares the detection proficiency between conventional phased array s-scan and Dual Matrix Phased Array.

Keywords: Ultrasonic, conventional PAUT, dual matrix array UT, single-sided access welds, simulation, focal law, probability of detection

1. Introduction

PAUT is vested with immense capabilities to perform high quality weld examination that meets the corresponding established code requirements and when PAUT is applied with appropriate focal law parameter selection it yields the best results. Elaborate discussion on choosing the appropriate focal law parameters has been discussed in our previous paper titled "Effect of focal law parameters on Probability of Detection in Phased Array Ultrasonic Examination using simulation and case study approach" presented at the 7th Middle East Non-Destructive conference held at Bahrain [1].

In general practices, the ultrasonic weld examination requires probe placement on both sides of the weld to completely cover the weld volume. If certain weld joint configurations restrict the probe placement to be at only one side of the weld, then those weld joints are specified as one sided access weld joints. The requirement for examination of one sided access weld is a common scenario faced in various industries which includes examination of pipe to reducer welds joints and other similar pipe to fitting weld joints. Mostly these weld joints are with weld crown ripples which deviates the ultrasound beam from its intended path and thus increase the difficulty in ultrasonic application of one sided weld examination.

Generally for any ultrasonic weld examination, it needs to be validated according to corresponding project requirement using appropriate demonstration block. It has been emphasized in ASME Section V Article 4 mandatory Appendix IX-435.8 [2] that one sided weld examination technique requires to be validated using appropriate demonstration block which shall contain two sets of flaws, one set on each sides of weld axis. This paper enumerates study of ultrasonic response of opposite side sub-surface Lack of Fusion (LOF) in one sided access weld joints using the ultrasonic examination techniques namely linear phased array tip diffraction technique, linear phased array third leg examination and DMA (Dual Matrix Array) ultrasonic technique.

2. Examination techniques

The various techniques applied for one sided weld examination have been listed below.

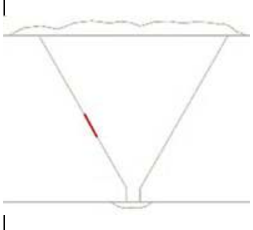
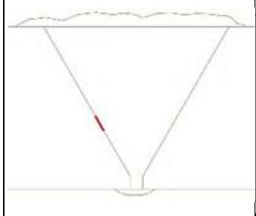
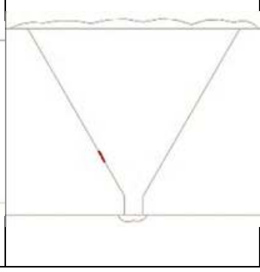
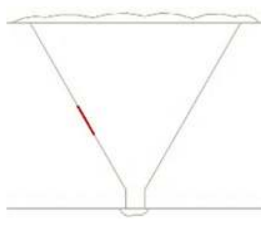
1. Conventional (Linear) Phased Array examination
    a. Tip diffraction technique for welds with crown
    b. Third leg examination for welds with crown ground flushed
2. Advanced (Dual Matrix) Phased Array examination for welds with or with-out crown.

The above mentioned techniques have been validated and their capabilities are evaluated through case studies involving both simulation [3] and practical approach.

3. Specimen selection

Welded specimens of two different thicknesses, 12.5 & 20 mm are chosen for this study. As LOF is the most commonly missed defect in one sided examination this has been chosen as the target. Each of these specimens contain two natural LOFs with varying length, height and position in the weld. All the LOFs are chosen on the skew 90 side and the dimensions of the LOFs are evaluated using linear phased array ultrasonic weld examination with probe placement at same side of LOFs (as of two sided weld examination) and listed in Table 3.1.

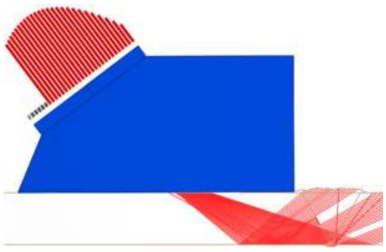
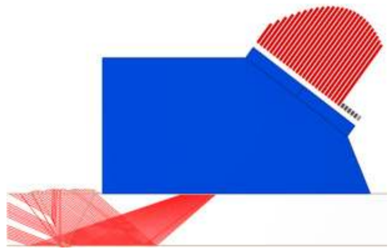
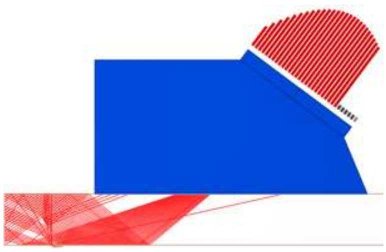
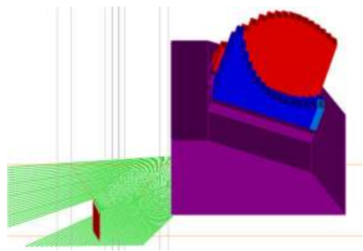
Table 3.1. LOF Dimensions

Specimen Thickness	12.5 mm		20 mm	
Defect	LOF 1	LOF 2	LOF 1	LOF 2
Depth	7	7.5	13.8	10.5
Length	10	12	14	10.75
Height	2.5	1.5	1.3	3.5
Volumetric position	-3.5	-3	-3.4	-5
Cross section view				

4. Scan plan

Conclusion from previous paper [1] has been used to generate the most appropriate scan plans for Phased Array examination. The scan plans are generated for both 12.5 & 20 mm thick specimens.

Table 4.1. Scan Plan Techniques

Scan plan 1	Scan plan 2
Conventional (Linear) Phased Array (Examination from skew 90)	Tip Diffraction Technique (Examination from skew 270)
	
Scan plan 3	Scan plan 4
Third Leg examination (Examination from skew 270)	Advanced (Dual Matrix) Phased Array (Examination from skew 270)
	

5. Objectives of case study

The objectives of the case study are

- To perform simulation and practical examination to detect skew 90 side LOFs using one sided weld examination namely linear phased array tip diffraction technique, linear phased array third leg examination and Dual Matrix Array ultrasonic technique from probe placement at skew 270.
- To analyze the examination sensitivity of all three selected one sided weld examination methodology based on LOF's amplitude response and its desirable signal to nose ratio.
- To conclude the most appropriate ultrasonic weld examination methodology for one sided weld configurations.

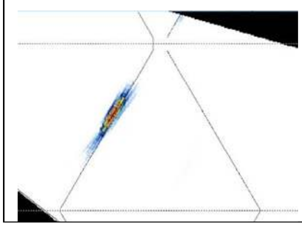
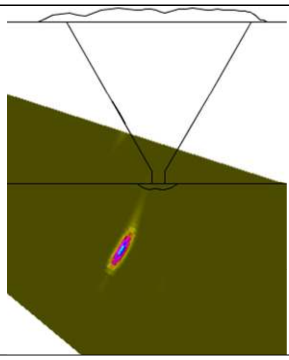
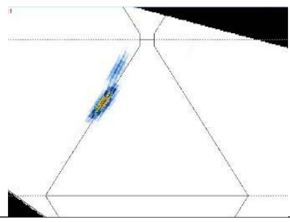
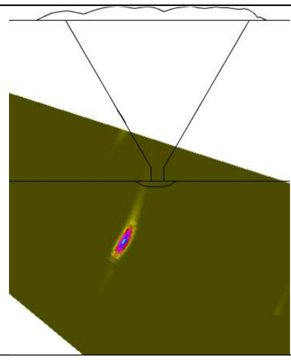
The scan plans as provided in section 4 and chosen LOFs are shown in section 3 are utilized to accomplish the objectives.

6. Case study 1: 12.5 mm

6.1 Conventional (linear) phased array technique

Results of Scan plan 1 (probe placed in same side of the LOF) over the two natural LOFs are shown in Table. 6.1. The technique has demonstrated (by both simulation as well as practical tests) good detection, resolution & sizing for both the LOFs.

Table 6.1: S-scan image from Scan plan 1 for LOF 1 (left) & LOF 2 (right)

LOF 1		**LOF 2**	
PRACTICAL	SIMULATION	PRACTICAL	SIMULATION
			

6.2 Tip diffraction technique

Tip diffraction technique (Scan Plan 2) constitute one sided weld examination which is based on tip diffraction of defects that majorily lies parallel to direction of ultrasond beam and results are tabulated in Table 6.2 & 6.3. In reference dB, it is observed that the skew 90 side LOFs (evaluated by scan plan-1) are missed in this one sided weld examination. It is due to the fact that ultrasonic response from same side of LOF is based on specular reflection, while ultrasonic response from the opposite side of the LOF is based upon tip diffraction echos of the fusion defect tips. In this case study, the reference dB is increased gradually and the defect tips are coniderably detected at additional dB of +25dB. However the additional dB depends on weld crown nature and may considerably vary case to case.

Table 6.2: S-scan image from Scan plan 2 for LOF 1

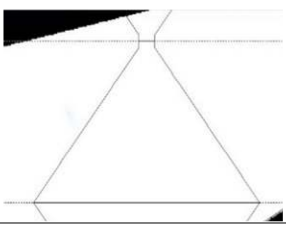
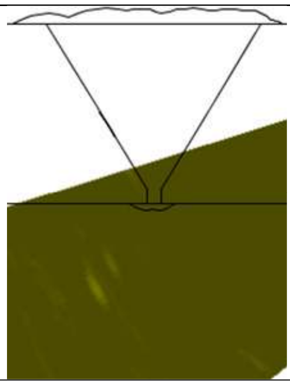
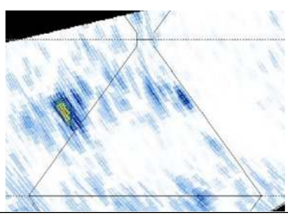
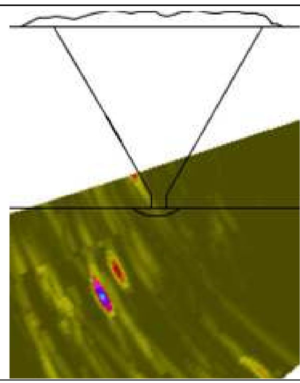
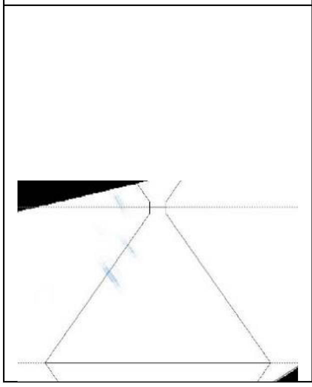
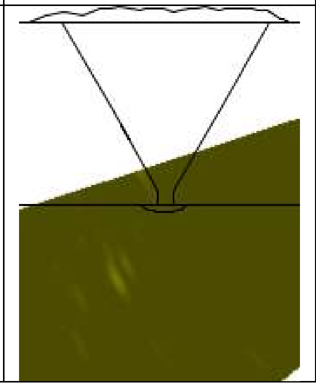
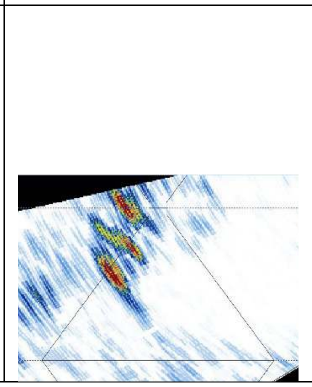
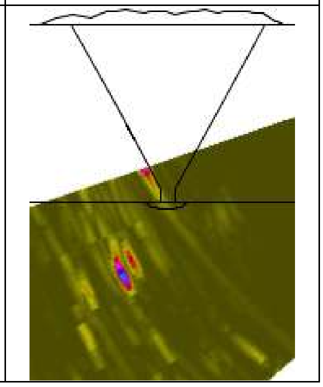
REFERENCE dB		**+25 dB**	
PRACTICAL	SIMULATION	PRACTICAL	SIMULATION
			

Table 6.3: S-scan image from Scan plan 2 for LOF 2

REFERENCE dB		+25 dB	
PRACTICAL	SIMULATION	PRACTICAL	SIMULATION
			

But it has to be noted that, increase in dB for detetion comes at the cost of increased noise level, which is undesirable. The signal to noise ratio is greatly reduced and the noise signals mix with the defect signals creating confusion for the interpretor. This technique can be applied over welds with weld crown but only with great caution of desirable signal to noise ratio.

6.3 Third leg examination

Third leg examination consititute another one sided examination which is based on specular refection from the third leg and results are tabulated in Table 6.4 & 6.5. This case study involves detection of the skew 90 defects by one sided weld examination from skew 270 (opposite side of the bevel) in the third leg. This technique is highly dependent on the smoothness of the weld cap as the ultrasonic beams get distorted and mode converted at the ripples of weld crown. Beams reflecting from weld crown and interacting with the defects always results in shift in position of reflectors. This is again a confusion for technician. Such technique has to be applied with great caution during data interpretation. This examination has to be applied with caution that additional dB required to evaluate the defect depends on the nature of weld crown. In this selected case study, an additional dB of + 12 dB is required above the reference dB. However, for a flushed weld cap, the LOF is detected with 100% sensitivity in third leg examination at the reference dB

Table 6.4: S-scan image from Scan plan 3 for LOF 1

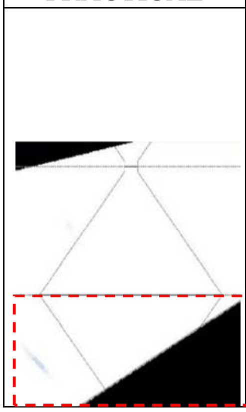
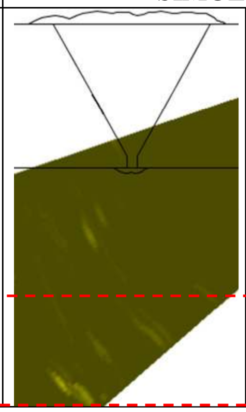
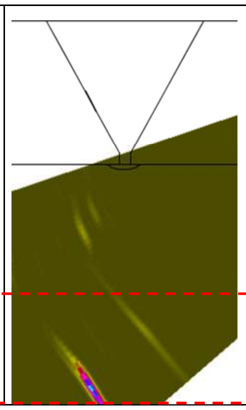
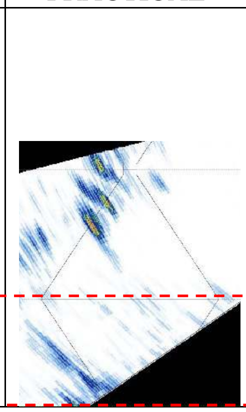
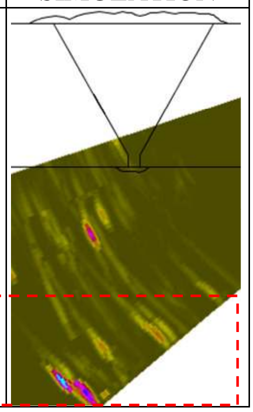
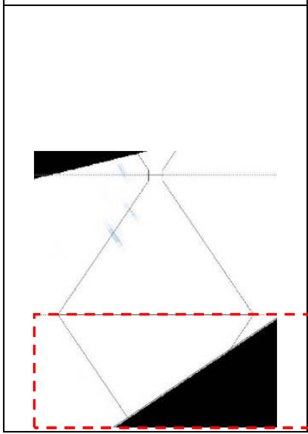
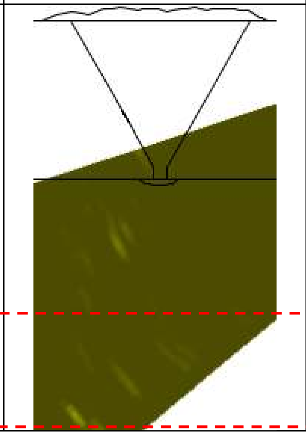
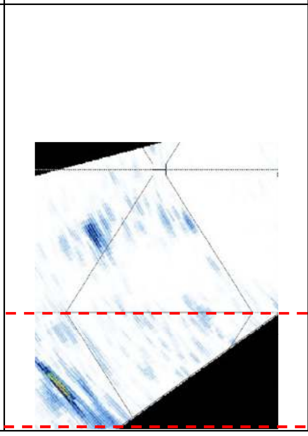
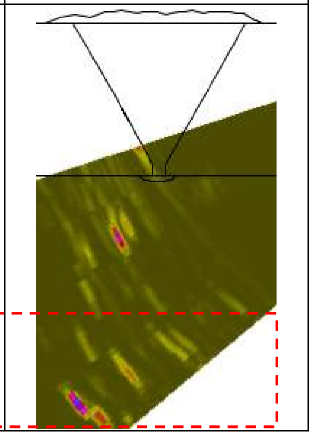
REFERENCE dB			+12 dB	
PRACTICAL	SIMULATION		PRACTICAL	SIMULATION
				

Table 6.5: S-scan image from Scan plan 3 for LOF 2

REFERENCE dB		+12 dB	
PRACTICAL	SIMULATION	PRACTICAL	SIMULATION
			

6.4 Advanced (dual matrix) phased array technique

Dual Matrix Phased Array technique based on Transit Receive Longitudinal (TRL) wave, in which Longitudinal wave is trasmitted by one transducer and is received by another. It is a promising technique for one sided weld examination with the advantage of sweeping wide range of angles (upto 87^o) and more better focusing option when compared to Linear array PAUT. For this study Dual Matrix Array probes of available pitches has been chosen and the best have been reported in the results.

Table 6.6: S-Scan image from scan plan 4 for LOF 1

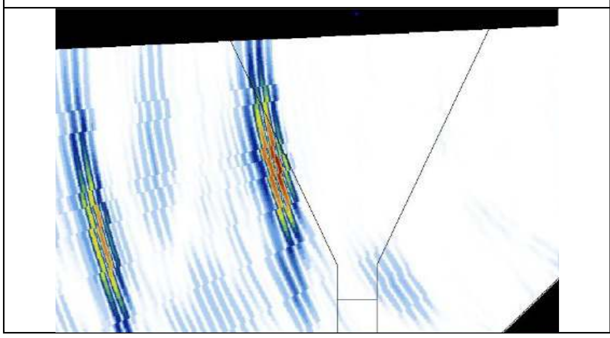
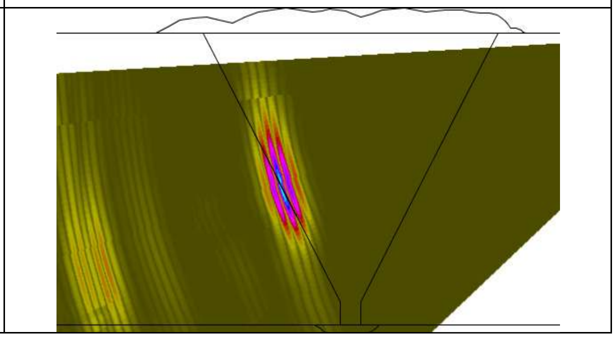
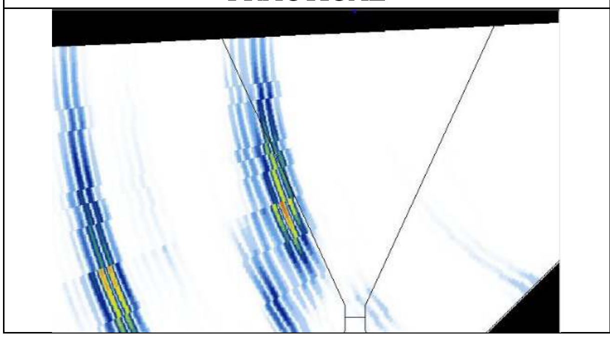
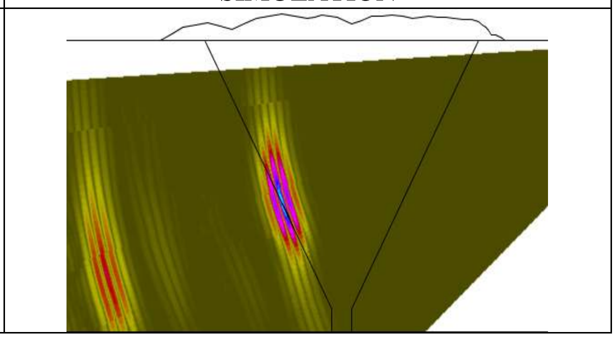
PRACTICAL	SIMULATION
	

Table 6.7: S-Scan imaged from scan plan 4 for LOF 2

PRACTICAL	SIMULATION
	

From Table 6.6 & 6.7 it is seen that scan plan 4 with appropriate focal law parameters is able to detect both the LOFs with accurate positioning. The advantage of this technique is that it can be applied over welds with crown without any additional dB requirement. The signal to noise ratio is considerably better compared to conventional PAUT single sided examination techniques.

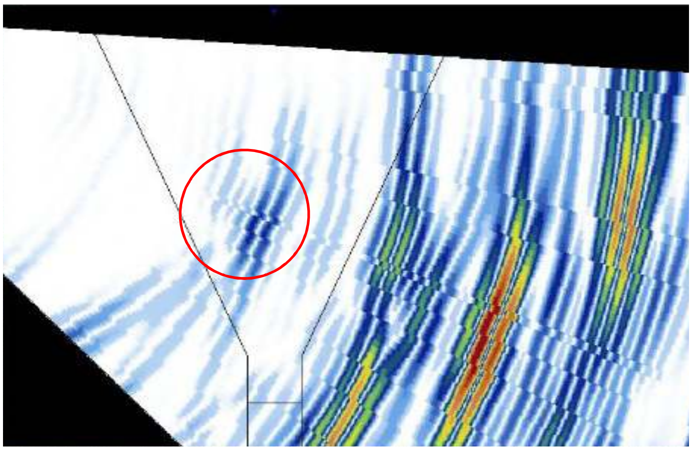


Figure 6.1: S-scan image using scan plan 4 for same side examination of LOF.

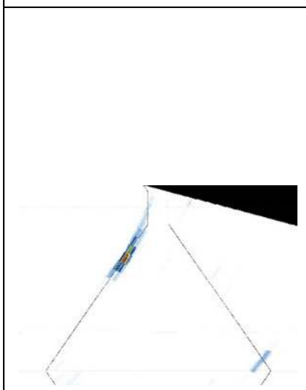
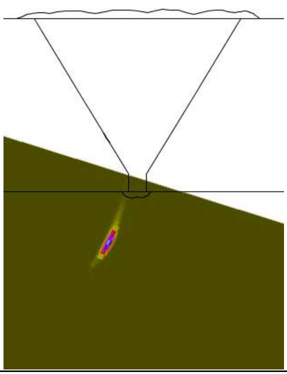
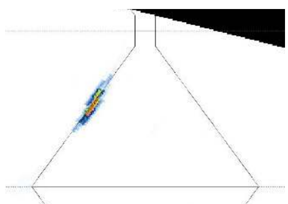
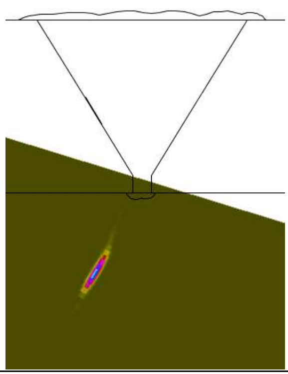
The scan plan 4 was used to perform examination from same side of the LOF but result with poor resolution and the result is as shown in Fig 6.1. For one sided weld examination of carbon steel application, it observes that a combination of conventional (Linear) phased array to cover same side weld volume (say, skew 90) and DMA for opposite side weld volume (say, skew 270) may be the best solution with higher probability of detection.

7. Case study 2: 20 mm

7.1 Conventional (linear) phased array technique

Results of Scan plan 1 (skew 90) over the two natural LOFs of 20mm thick are shown in Table. 7.1. This technique has demonstrated (by both simulation as well as practical tests) good detection, resolution & sizing for both the LOFs.

Table 7.1: S-scan image from Scan plan 1 for LOF 1 (left) & LOF 2 (right)

LOF 1		LOF 2	
PRACTICAL	SIMULATION	PRACTICAL	SIMULATION
			

7.2 Tip diffraction technique

Similar to the results seen in case study of 12.5mm thick, at reference dB it is observed here that the skew 90 side LOFs (evaluated by scan plan-1) are missed in this one sided weld examination. In this case study, the reference dB is increased gradually and the defect tips are coniderably detected at additional dB of +25dB for LOF 1 and at additional dB of +20 dB for LOF 2 and tabulated in Table 7.2 & 7.3. However the additional dB depends on weld crown nature and may considerably vary case to case.

Table 7.2: S-scan image from Scan plan 2 for LOF 1

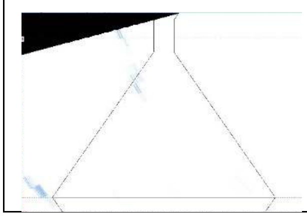
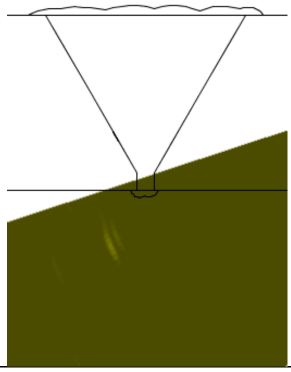
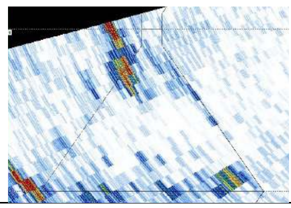
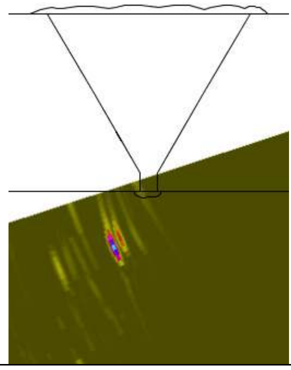
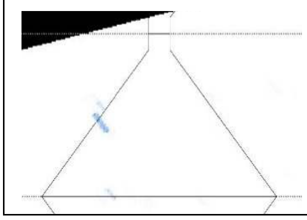
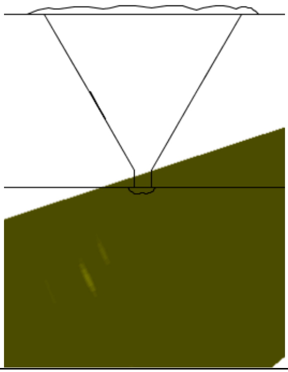
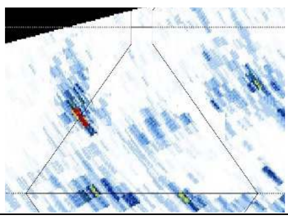
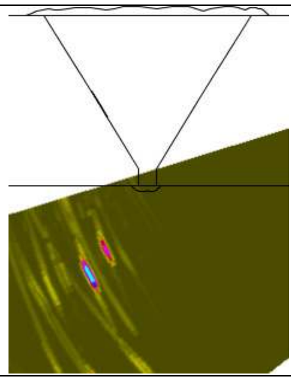
REFERENCE dB		**+25dB**	
PRACTICAL	SIMULATION	PRACTICAL	SIMULATION
			

Table 7.3: S-scan image from Scan plan 2 for LOF 2

REFERENCE dB		**+20dB**	
PRACTICAL	SIMULATION	PRACTICAL	SIMULATION
			

7.3 Third leg examination

Similar to case study of 12.5mm thick, at reference dB it is observed that the skew 90 side LOFs (evaluated by scan plan-1) are missed in this one sided weld examination. In this case study, the reference dB is increased gradually and the defect tips are coniderably detected at additional dB of +12 dB for LOF 1 and at additional dB of +15 dB for LOF 2 and tabulated in Table 7.4 and 7.5. The additional dB depends on weld crown nature and may considerably vary case to case. The LOF is mispositioned due to beam deviation at the unflushed weld crwon. However, for a flushed weld cap, the LOF is detected with 100% sensitivity in third leg examination at the reference dB.

Table 7.4: S-scan image from Scan plan 3 for LOF 1

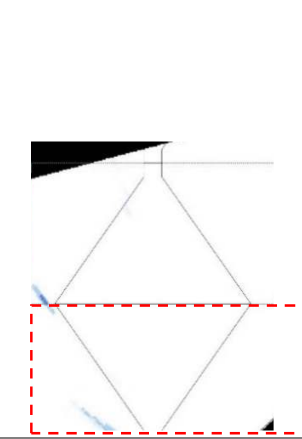
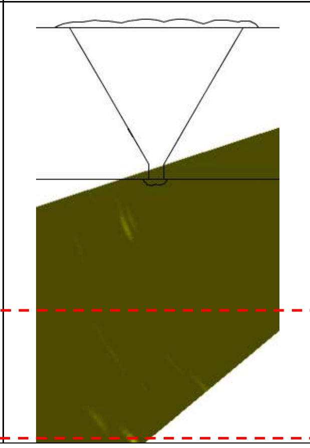
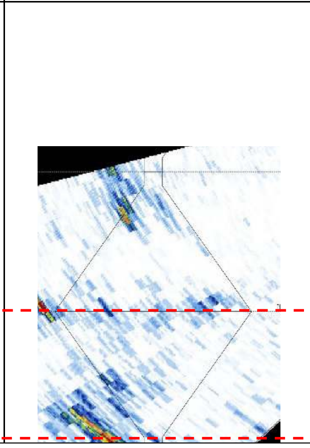
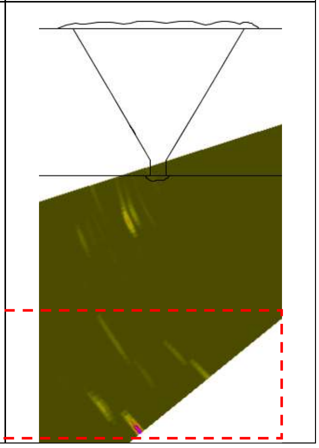
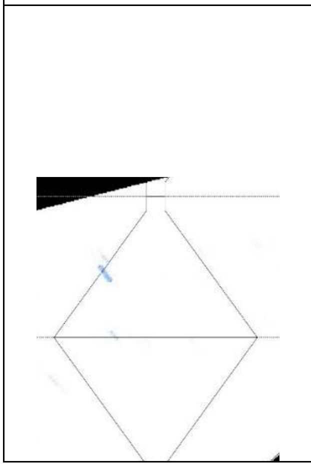
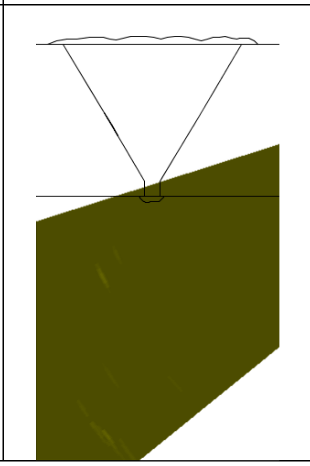
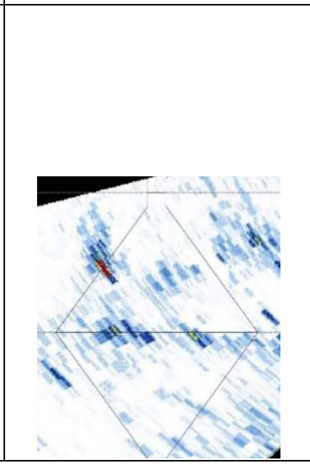
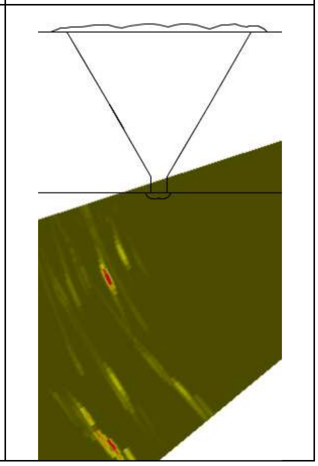
REFERENCE dB		+12 dB	
PRACTICAL	SIMULATION	PRACTICAL	SIMULATION
			

Table 7.5: S-scan image from Scan plan 3 for LOF 2

REFERENCE dB		+ 15 dB	
PRACTICAL	SIMULATION	PRACTICAL	SIMULATION
			

7.4 Advanced (dual matrix) phased array technique

Table 7.6: S-Scan imaged from scan plan 4 for LOF 1

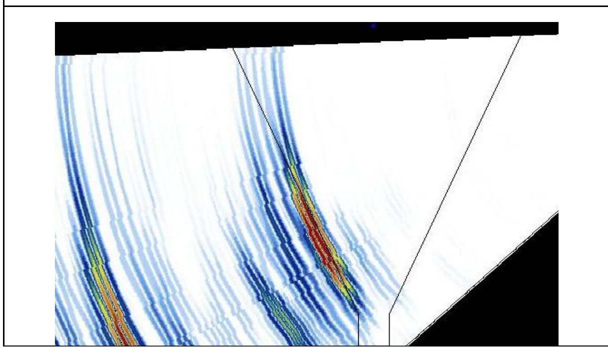
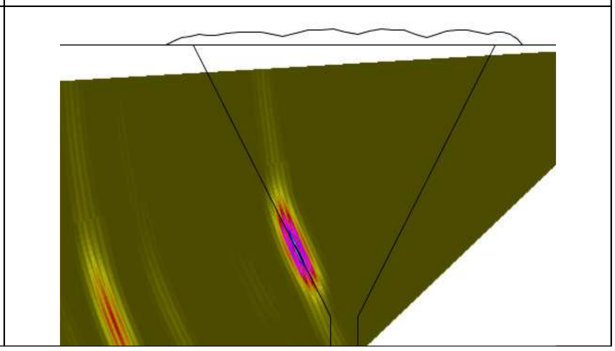
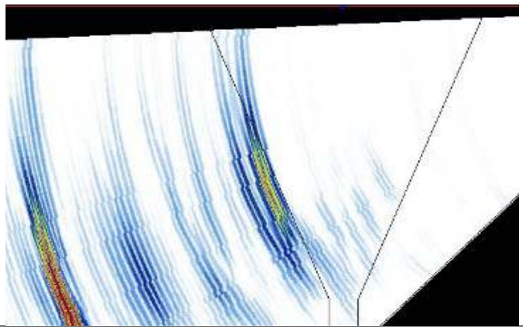
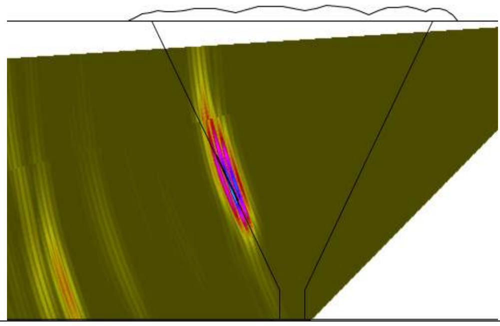
PRACTICAL	SIMULATION
	

Table 7.7: S-Scan imaged from scan plan 4 for LOF 2

PRACTICAL	SIMULATION
	

From Table 7.6 & 7.7 it is seen that scan plan 4 with appropriate focal law parameters is able to detect both the LOFs with accurate positioning and similar to results in case study of 12.5mm thick. Signal to noise is very high and this is achieved at calibration sensitivity itself.

8. Conclusion

- One sided weld examination using linear phased array tip diffraction technique needs significantly more additional dB to interpret the tip diffraction. It could be applied in as welded condition but highly limited with poor signal to noise ratio in practical aspect.
- One sided weld examination using linear phased array third leg technique needs nominal additional dB. It could be applied in as welded condition but highly limited with considerable mis-position of defect in practical aspect. However could be relevant for smooth and flush grinded welds.
- One sided examination using dual matrix array technique with appropriate focal law parameters is able to detect LOFs with good signal to noise ratio and relatively accurate positioning. It is significantly better than above linear phased array techniques.
- For one sided weld examination of carbon steel application, a combination of conventional (Linear) phased array to cover same side weld volume (say, skew 90) and DMA for opposite side weld volume (say, skew 270) may be the best solution with higher probability of detection
- As a future scope, DMA technique can be studied for weld examination with complex configuration including nozzle examination etc. The next phase of this study is estimated to study the weld application over exotic materials like austenitic stainless steel welds etc.,

9. Reference

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2. *ASME Boiler Pressure Vessel Code, Section V – Nondestructive Examination, ASME, July 1* 2013

3. CIVA UT Module, ENDE15T014 Rev. 01, 2015