Use of Ultrasonic Phased Arrays for Examination of Austenitic Steel welds – An experience

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Abstract

Penetration of Ultrasonic waves in the frequency range commonly used in material testing is very limited in case of Austenitic welds due to (1) anisotropic grain structure inherent in the austenitic materials, (2) Cast microstructure of the weld pool and (3) Preferential orientation of grain growth (elongated grains or dendrites). The size, elastic anisotropy and preferential orientation of grains result in the following effects: (1) High sound scattering; (2) Mode conversion; (3) Beam distortion and (4) Variation in ultrasonic velocity in the material.
The problems may differ based on the product form e.g. cast, rolled, drawn or forged etc., welding process and parameters including heat input and heat treatment conditions. Conventional ultrasonic shear wave and longitudinal wave angle beam techniques have long been tried to evaluate the welds with very limited success. Developments in the ultrasonic Phased Array technology have got much success in overcoming those limitations of ultrasonic testing. Use of PR Modules (Pulser-receiver) with 1D or 1.5D linear probes & Dual Matrix Array probes enhanced the detection capability of the system even in thicker welds with accurate focusing ability. A few air cooler headers in refinery service were manufactured with SA 240 Gr. 316L material of 10mm and 20mm thick welds by manual metal arc welding. The coolers conform to ASME Sec VIII Div. 1 Code of construction. Therefore demonstration and qualification of the procedure was a requirement of the Code. Use of manual ultrasonic did not result in adequate detection of all the induced flaws in a mock up weld. Hence ultrasonic Phased Arrays have been used and resulted in good detecting capability and even accurate sizing of all the induced flaws in the welds and the validation of the procedure were performed satisfactorily.

Key words: Ultrasonic Phased Arrays, Anisotropy, Austenitic welds, 2D linear Array probes.

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1. Introduction:

Air cooler stationary & floating header boxes has been manufactured in accordance with the requirements of ASME Sec VIII Div. 1 2013 edition. The coolers are intended for lethal services and hence require 100% volumetric NDT i.e. either Radiography or automated / semi-automated Ultrasonic testing. Since the weld design excludes use of satisfactory Radiography, Phased Array Ultrasonic testing has been selected for examination of the welds. Typically the welds are of full penetration corner welds with one side scanning access. Please refer to the figure-1 below for weld geometry:

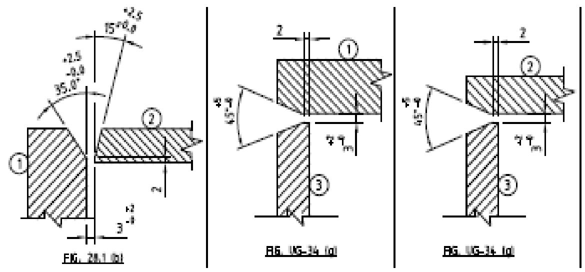

Figure – 1: Weld geometry

As seen from the figure, that access for full scanning of the weld volume is not possible due to typical weld geometry. A manual ultrasonic examination was proposed first; however the manual UT was not successful because of the following reasons:

1. The material is Austenitic Stainless Steel having highly coarse grain microstructure.
2. The weld is made of Stainless Steel electrode, which provided even coarser grains and preferential orientation of grains (dendritic) having cast like micro structure.
3. Inadequate access for scanning.

As a result, a more reliable ultrasonic technique with automatic data acquisition has been proposed because of the following:

1. Phased arrays have the capability of generating focused sound beams to the pre-determined depth.
2. Generation of sound waves at various angles by electronic steering of the probe angles.
3. Automated data acquisition by the most advanced software.
4. Flaw accurate positioning by encoding.

The main advantage of PAUT is full data acquisition controlled by powerful software which makes it possible the reliability, repeatability and reproducibility of the test.

2. Stainless Steel Weld characteristics:

The term austenitic covers a variety of materials and material combinations, including austeniticstainless steels and nickel chromium alloys suchas “lnconel”, “lncoloy”, etc. The capabilities of Ultrasonic for the examination of welds in austeniticmaterials are restricted compared to theferritic case because of the presence of largeelongated anisotropic grains (dendrites), oftenforming an ordered columnar structure, which are characteristic of the austenitic weld metal. Thistype of grain structure can lead to anisotropicultrasonic behavior contrasting with the isotropicbehavior of homogenous welds made in carbon orlow alloy steels. The size, the arrangement, and the elasticanisotropy of the different grains result in highscattering associated with mode conversion effects,beam distortion, and a variation of ultrasoundvelocity with direction and position in theweld. The scattering of energy is observed as arelatively high noise level (grass) and high attenuation. The problems which occur in ultrasonic testingof austenitic welds differ according to the parentmaterial production method (rolled, drawn, forged,or cast), the weld processes, and the heat treatment as well as the composition of the parent andweld metals.

3. Effect of Austenitic Microstructure for Ultrasonic Wave Propagation:

The effect of austenitic structures on the behavior of ultrasound depends primarily on grain size and preferred orientation of the grains with respect to fusion faces of the welds. Coarse grain cast structures typically found in SS welds have marked effects, leading to increased scatter and attenuation, variations in sound velocity, and often to beam-distortion. The effects are primarily due to the anisotropic nature of the austenitic grains.

Many of the ultrasonic characteristics of austeniticwelds derive ultimately from the anisotropicelastic properties of the columnar grains whichform the weld. Generally the average grain sizes of the Austenitic welds are comparable to the extent of about 1/10th or higher the ultrasonic wave length deployed for testing of such welds. The resulting mode conversionand scattering effects at grain boundaries areimportant sources of noise and of spurious indications.The effect of the austenitic welds structureis that ultrasound propagation is sensitive tothe angle of the wave-front with respect to thegrain axes. The dependence on this angle changesdramatically as the wave mode under considerationis changed from the common vertically polarizedshear waves (SV), to longitudinal waves (L)and to horizontally polarized shear waves (SH).An important factor is that when traveling throughthe coarse grained anisotropic material the wave-frontsare not generally at right angles to thebeam axes. This means that the effective directionof the beam (maximum energyflux) in anisotropicweld metal can differ from the nominal beamdirection.

In practice, for weld inspection it is not possibleto predict the beam width except for simplifiedstructures. Thismeans that defect size estimation by techniqueswhich rely on knowledge of the beam shape (e.g.20 dB drop method) will not be satisfactory insituations where the beam is distorted in its paththrough anisotropic weld metal.

Because of variations in beam shape, amplitudemethods for defect evaluation are less reliable foraustenitic than for ferritic welds.

Reflection at the base metal – weld interface, refraction at the interface and mode conversion at the interface can occur and produce spurious indications which may hinder proper interpretation of indications.

A major practical problem in the ultrasonicexamination of austenitic welds is the occurrenceof severe attenuation and of back scattered ultrasound(grain noise) which varies with the directionof the ultrasonic beam in the weld material.A number of mechanisms areinvolved. Combined with a high grain-noise level,the attenuation can cause considerable problemsin obtaining an adequate signal-to-noise ratiowhen examining welds which are several centimetersthick.The scattering increases with grainsize, frequency, and elastic anisotropy, and alsodepends on materials properties, density andsound-velocity. All these can givea large and variable apparent attenuation which isdirection dependent.

4. Procedure for Ultrasonic Phased Arrays:

Ultrasonic scan plans have been generated to understand the covered volume of the welds with longitudinal wave as well as shear wave angle and normal beam probes at different positions. A sample scan plan is appended below for a 10mm to 20mm Tube sheet to top and bottom plate weld geometry:

Probe	Frequency	Probe Size (Ø)	Depth Range	Index Offset	Scan
PA-01 (SW)	5MHz	16X0.6mm	0-10mm	-35mm (From Edge)	Face-A
PA-02 (LW)	5MHz	16X0.6mm	0-30mm	-10mm (From Edge)	Face-B
PA-03 (LW)	5MHz	Gr-1(49X0.6mm)-0 Deg Gr-2(16X0.6mm) ± 30 Deg	0-20mm	15mm (Wedge Front-Edge)	Face-A
PA-04 (LW)	5MHz	Gr-1(49X0.6mm)-0 Deg Gr-2(16X0.6mm) ± 30 Deg	0-20mm	25mm (Wedge Front-Edge)	Face-B

TABLE-1: SCAN PLANS

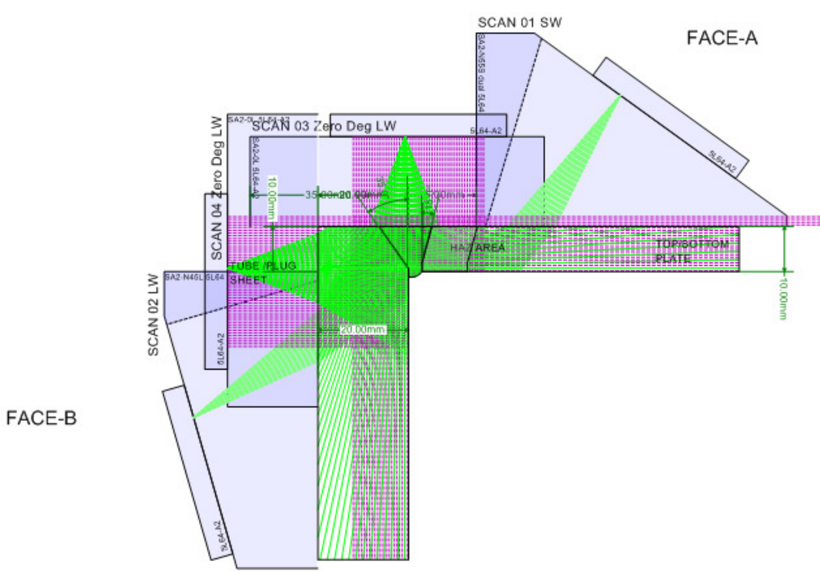

FIGURE-1: (SCAN PLAN FULL)

FIGURE-2: WELD GEOMETRY

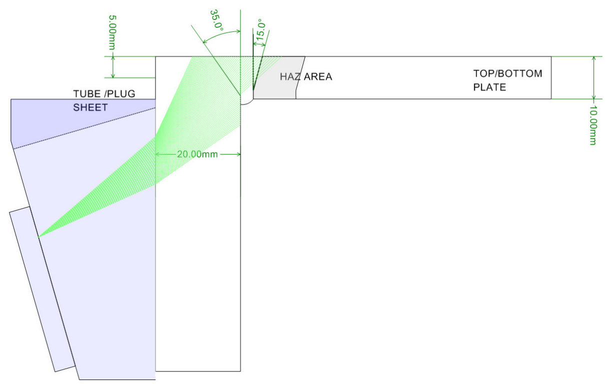

FIGURE-3: LW WAVE SCAN

5. Results of Test:

The results of the test were found quite satisfactory with all the intended and induced flaws have been properly detected, sized and evaluated as per the requirements of the construction code (ASME Sec VIII Div. 1). The procedure validation was quite satisfactory.A sample result of the indications observed is shown below. The weld is scanned as per the above scan plan.

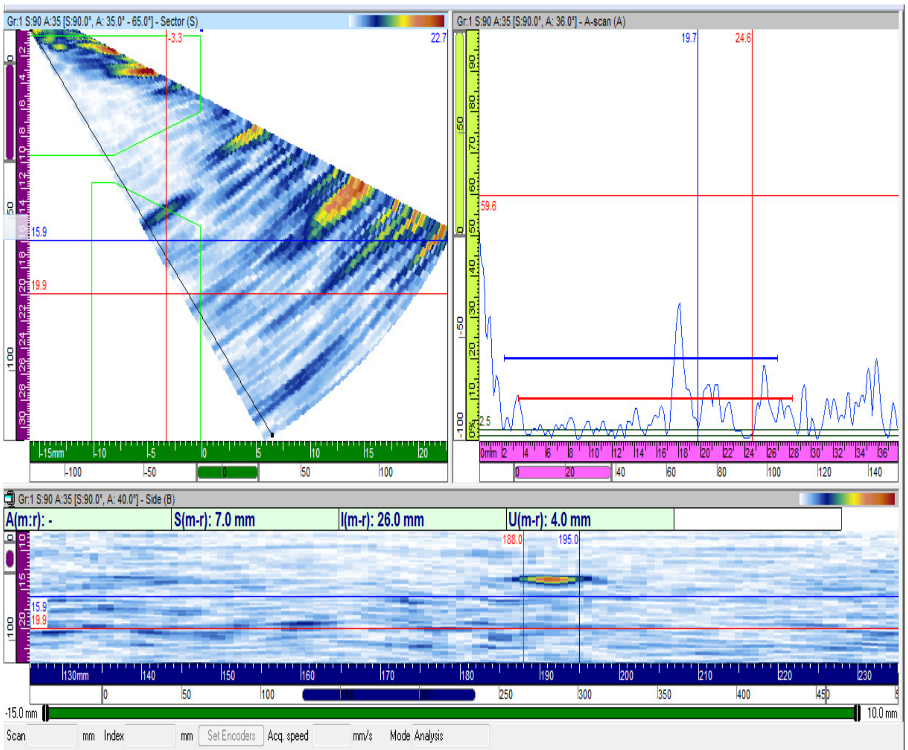

FIGURE-4: FLAW DETECTION BY LW WAVE (SECTORIAL SCAN 35^0 - 60^0)

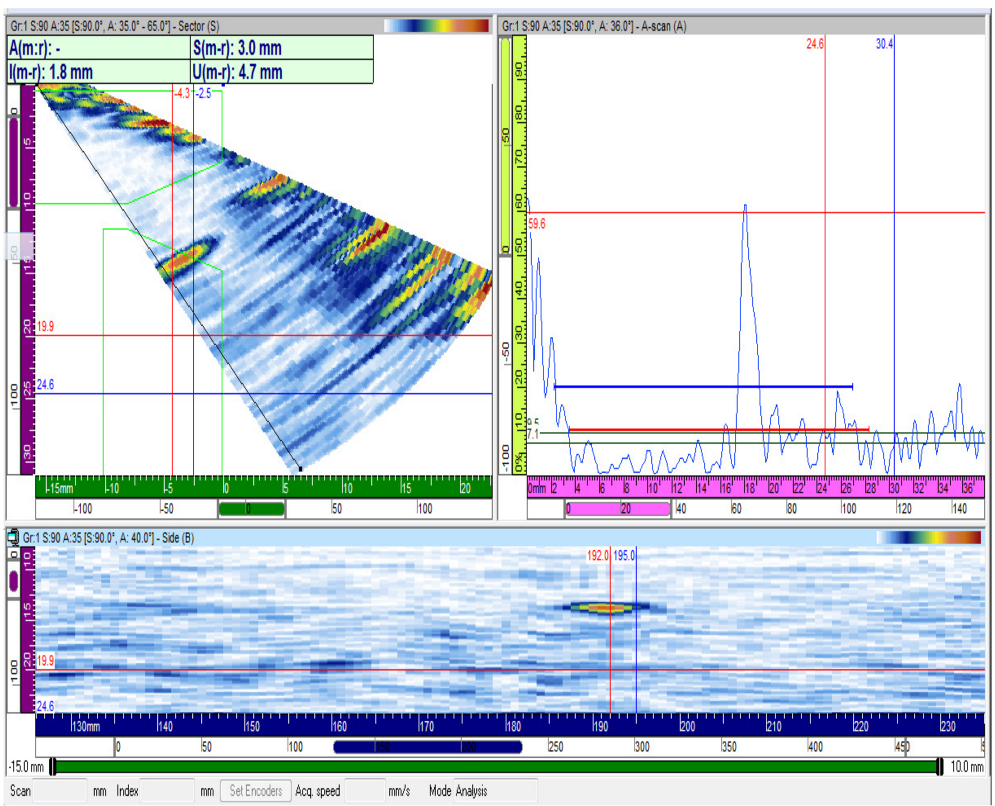

FIGURE-5: FLAW DETECTION BY LW WAVE (SECTORIAL SCAN 35^0 - 60^0)

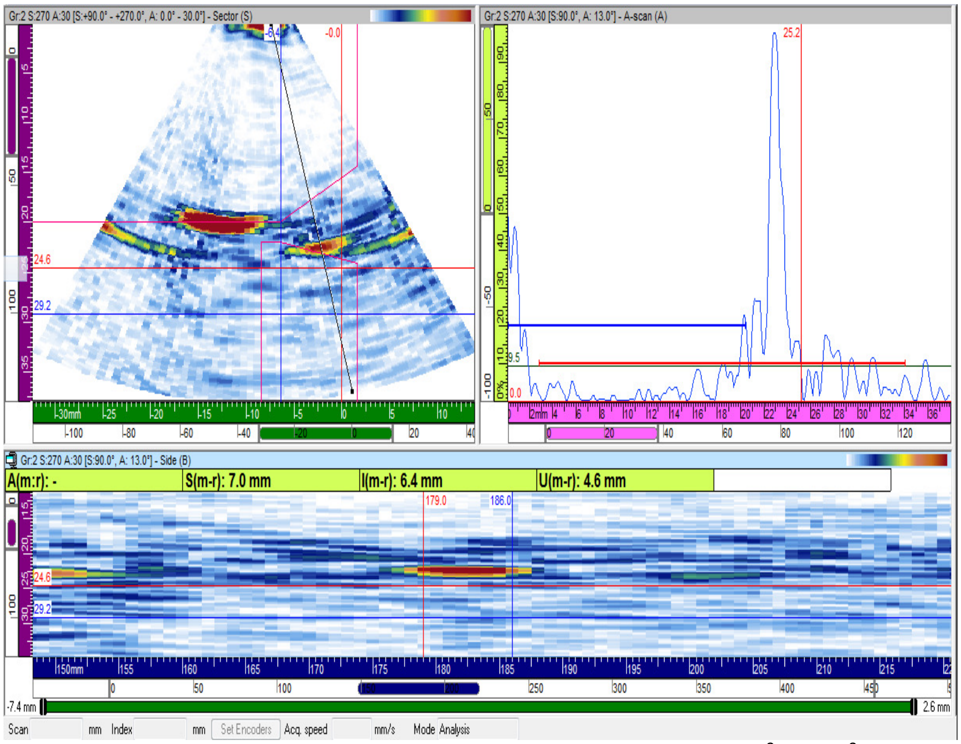

FIGURE-6: FLAW DETECTION BY LW WAVE (NORMAL -30^0 - $+ 30^0$)

From the figures above, it is found that the longitudinal sound beam can travel through the austenic large grains and detect the flaws which are at the oppsite surface of the weld. While trying to detect those flaws by convetional UT and also bt shear wave phased arrays, we could not be able to detect those flaws. This is because of the large austenitic grains which blocks the passage of shear waves because of their inherently smaller wave length comparable to grain sizes. Convetional ultrasonic also failed to detect such flaws even by using LW angle probes because of unfocussed sound beam. Phased Arrays has a unique capability of beam steering and right focussing to the intended flaw depth which enhances the detectibility.

6. Conclusion:

This paper is only a presentation of experience gained during ultrasonic examination of weld of Austenitic stainless steel. Since ultrasonic examination of such welds is really difficult, if at all possible, and since the weld type is mandatorily required to be examined by NDT volumetrically and moreover, the weld geometry excludes the use of satisfactory Radiography, the only option is to use semi autometed Phased Arrays. After successful completion of procedure demonstration, we have completed the whole project without any hindrance. Hence, it is concluded that Phased arrays can be successfully used where other techniques failed to provide satisfactory results.

References:

1. IIW Handbook of Ultrasonic testing of Austenitic welds.
2. ASME BPV Code Sec V: 2013
3. Olympus Handbook of Phased Array Ultrasonic Testing.