CSA W59 advanced inspection methods

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Abstract

The ASME code permits the use of digital radiography and advanced Ultrasonic testing (AUT) methods, such as Time of Flight Diffraction (TOFD) and Phased Array(PA) for code sections dealing with Boilers, Pressure Vessels and Nuclear reactors. Advances in inspection technologies are finding their way into Canadian standards. Recently revised CSA W59 Standard, now permits the use of these technologies on bridge structures provided there is a written agreement between the Engineer and the Contractor, prior to the examination through clauses 8.1.6 and 8.2.12 of the standard. An overview of these new methods will be presented. A short research program was initiated by Mistras-Metaltec with collaboration from various partners in early 2012. Preliminary test results of inspection with conventional RT & UT methods and advanced methods on two experimental plates with defects will be presented to provide a comparison.

Keywords: Digital Radiography (DR), Computed Radiography (CR), PAUT & TOFD

1. Introduction

Technological advances take time to find their way into National and International standards, since most of these standards are developed through consensus between the members of the technical committees representing the stakeholders. At CSA, the technical committees have a balanced matrix between the User, Regulator, Producer & General Interest categories. It is important to note that members of these committees work benevolently to create these consensus standards sharing their expertise to protect public safety.

The CSA W59-13 standard's Technical committee is currently chaired by Mr. Craig Martin, P. Eng from the CWB Group. In early 2009 his Technical Committee manifested interest to include advanced inspection methods in the body of the text. Since then, the committee has worked hard and the new edition CSA W59-13 is now finalized. This new edition will be available to public in the next few months.

The principal author was keenly interested to help promoting these new technologies. A demonstration of the advanced UT Phased array was performed to the Technical committee in November of 2009 and then he launched a research and development program in search of these greener NDE technologies to create the required demonstration pieces for comparison. These demonstration pieces with real weld defects, would be needed to understand the new technologies. The results and the status of this evaluation is covered later in this paper.

2. Description of the Alternate radiation imaging systems

Currently the preferred method to inspect welds is to use radiography with X-Rays or radioisotopes. This film method is a non-green technology. Depending on the type of radiation used and the weld thickness inspected, the clarity of the image depends on the procedure, shooting & film development techniques and experience of the operator. If the radiographic image quality and the film density are not to the prescribed quality per code requirements, the welds must be reshot. These reshoots entail production delays for the fabricator and a loss of revenue for the inspection company, more importantly a loss of efficiency for all involved. The reports are written out on paper and are then sent by mail or e-mail. The radiographic films are stored in appropriate storage facility.

Alternate radiation imaging systems are relatively greener technologies than convention films. The most popular system in this regard is the Computed Radiography (CR) and the Digital Radiography (DR).

These new technologies increase productivity without sacrificing safety and quality. CR results are available in matter of minutes after the exposure and DR results can be real time with a wireless module. This promotes same shift response to acceptance results, defects and rework requirements. The long delays caused by reshoots in conventional film radiography is practically eliminated producing high throughput.

2.1. Computed Radiography (CR)

Computed radiography works similarly to film-based radiography, but instead of film, a flexible phosphor imaging plate (the same size as film that fits in a standard film cassette) is exposed and the latent image stored within it. It’s then taken to a reader, which uses a laser and detector to scan the latent image from the digital phosphor imaging plate.

In most cases this technology can be easily retrofitted into film-based systems, eliminating the need for film, chemicals, processing lab, equipment and storage. (Fig.1)

Figure 1 Computed Radiography portable scanner from GE, phosphor digital imaging plates from GE & Kodak/Carestream

2.2. Digital Radiography (DR)

Digital Radiography (DR)[1] (Fig. 2) refers to flat panel x-ray detectors. A DR system is equipped with a fixed size pixilated detector that translates radiation directly into an electrical charge. That charge is sent to a processing unit which assembles the image without processing. The advantage of DR is that it can produce an image immediately after the exposure by moving the latent image directly from the detector using the electronics integrated with the detector.

For most field Computed Radiography applications the SE-75 source is generally the safest and most practical choice for optimum quality results.[2] The combination of computed radiography with the lower energy Selenium 75 radiography proves additional benefits.. Typically, weld images can be magnified up to 400X and can measure a defect as small as 0.001 in. Because Selenium 75 is a lower energy radiation source, the lower wavelength provides higher contrast. While the exposure times are slightly longer, it provides a higher sensitivity image.

Figure 2 DR system showing a wireless module and a portable X-ray tube - courtesy GE & Mistras/VMI

The choice of Selenium 75 as the energy source has additional advantages. When used with a tungsten collimator, it is possible to confine the boundary to a much smaller area than using Iridium. This allows site personnel to safely continue working in adjacent areas without disruption.

CR & DR systems have many additional advantages, such as

- Decreased exclusion boundaries.
- Decreased exposure time of almost 70% of film.
- Image processing time is much shorter
- Digital image can be interpreted, marked, and annotated using mouse/keyboard instead of grease pencil.
- Digital image can be shared, e-mailed, and exported.
- The CR Digital imaging plate can be reusable many times - between 300 to 800 times
- DR systems with wireless option allows image review at a unique viewing station location.
- Data can be stored on DVD or sent on the net or printed as films for storage

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[1] Youtube video - DR : http://www.ge-mcs.com/en/radiography-x-ray/digital-x-ray/dxr250c-w.html

[2] Private communication with Mr. Marc Turmel, ing marc.turmel@mistrasgroup.com

Hurdles to overcome relate to the following items:

- Overcoming the Film Mind Set
- CR requires investment in scanners and Digital imaging plates
- CR plates must be protected from humidity
- DR Flat plate panel requires investment and care in handling
- More education is required to overcome lack of knowledge of the technology by stake holders
- Lack of Subject Matter Experts
- Lack of Skilled Work Force

2.3. Overcoming the film mind set : Film vs. CR

More often than not, use of new technologies often face the hurdle of overcoming perceptions. Most of the veteran radiographers have a reputation to live up to, hence will be more comfortable with the technologies they know, rather than trying something new on a job site, where time is of the essence and there is no time available for reshoots and experimenting. Work published by Mr. R.J Pardikar [3] at the World NDT conference (2008) provides objective evidence of CR vs. film for sensitivity resolution. Some of his work is cited here for ease of understanding :

"The experimental study was carried out to evaluate the quality of radiographs achieved with imaging plates (GE IT Imaging plates, IPCII-High speed, and IPS-III High Contrast) and Laser processing using scanner GE IT-CR 100, and comparison was made with the performance of Agfa D7 and D4 films. Both ASTM strip hole IQI and wire type IQI were used for assessing the contrast sensitivity. "

Table.1. Hole type IQI Sensitivity with Ir-192

Steel weld thickness,mm Relative exposure w.r.t Agfa D7	High speed IP (0.25)	High contrast IP	Agfa D 7	Agfa D 4
30	30-1T	30-1T	30-1T	30-1T
40	35-2T	35-1T	35-2T	35-1T
50	35-2T	35-1T	35-4T	35-2T

"The selection of IQI was done based on the thickness of the job. The thickness of the Image Intensifying screens and the exposure time to achieve the required optical density and sensitivity for the specific Phosphor imaging plates, were arrived on trial and error basis as there were no exposure charts available for Imaging plates."

[3] 17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China entitled 'Digital radiography and Computed radiography for Enhancing the Quality and Productivity of Weldments in Boiler components' by R.J. PARDIKAR, SDGM / NDT, BHEL, Tiruchirappalli,Tamilnadu-620014. Tel:+91-431-2575237,Fax:+91-431-2520730. e-mail:rjp@bheltry.co.in

Table.2. Hole type IQI sensitivity with Co-60

Steel weld thickness, mm Relative exposure w.r.t Agfa D7	High Contrast IP	Agfa D 7	Agfa D 4
40	35-1T	35-2T	35-1T
60	40-2T	-	40-2T
80	50-2T	50-2T	50-2T
90	50-2T	50-2T	50-1T
110	-	50-2T	50-1T

Table.3. Wire type IQI Sensitivity with Co-60

Steel weld thickness,mm Relative exposure w.r.t Agfa D7	Required wire dia in mm	High contrast IP	Agfa D 7	Agfa D 4
80	1.27	-	0.63	0.6
90	1.27	0.8	1.25	0.8
110	1.6	1.25	1.25	1.25

Table.4. Hole type IQI Sensitivity with 4 MeV Linac

Steel weld thickness,mm Relative exposure w.r.t Agfa D7	High contrast IP	Agfa D 7	Agfa D 4
80	50-2T	50-2T	50-1T
90	50-2T	50-1T	50-1T
110	50-2T	50-2T	50-1T
160	80-2T	80-1T	80-1T

Table.5. Wire type IQI Sensitivity with 4 MeV Linac

Steel weld thickness,mm Relative exposure w.r.t Agfa D7	Required wire dia in mm	High contrast IP	Agfa D 7	Agfa D 4
80	1.27	-	0.8	0.5
90	1.27	1.25	-	0.4
110	1.6	1.25	-	1.25
160	2.5	-	2.5	1.25

"From the test results shown in the above tables, the following conclusions can be drawn."

"In the case of Ir-192 source, for 50mm Steel thickness, the High Speed IP gives a hole type IQI sensitivity of ASTM 35,2-2T (1.75 %) which is better than, the corresponding value (ASTM 35, 2-4T) achieved by Agfa D7 film (High Speed film). Similarly, the High contrast IP gives a sensitivity of ASTM 35,2-1T,which is superior to the corresponding value (ASTM 35,2-2T) given by a fine grain film Agfa D4."

"In the case of the Co-60 source even at 90 mm thickness, a High Contrast IP gives sensitivity on par with Film. Table (2) shows the performance results with Hole type IQI, which shows the sensitivity ASTM 50, 2-2T, achieved by both IP and Film. Whereas the Table (3) shows the same test conducted with Wire type IQI, which clearly tells that IP has achieved a sensitivity of 1.25 % on par with Films.

Table (4) and Table (5) show the Sensitivity values achieved, when 4 MeV Linac is used, with Hole type IQI and Wire IQIs respectively .The sensitivity is at par with Agfa D7 film."

2.4. Digital Radiography (DR) vs. Computed Radiography(CR)

Digital radiography flat panels are far more sensitive than the phosphor imaging plates which are flexible and can be wrapped around a pipe, similar to a film technique. The following comparative tests teach the findings. The following example shows considerably less exposure time with DR for equivalent or better sensitivity of the 6" schedule 40 pipe shot with Iridium 192. (Fig. 3). It also follows that the enclosures required for performing the radiography with DR can be smaller, however, the responsible radioprotection person from the contractor should be consulted for the required analysis.

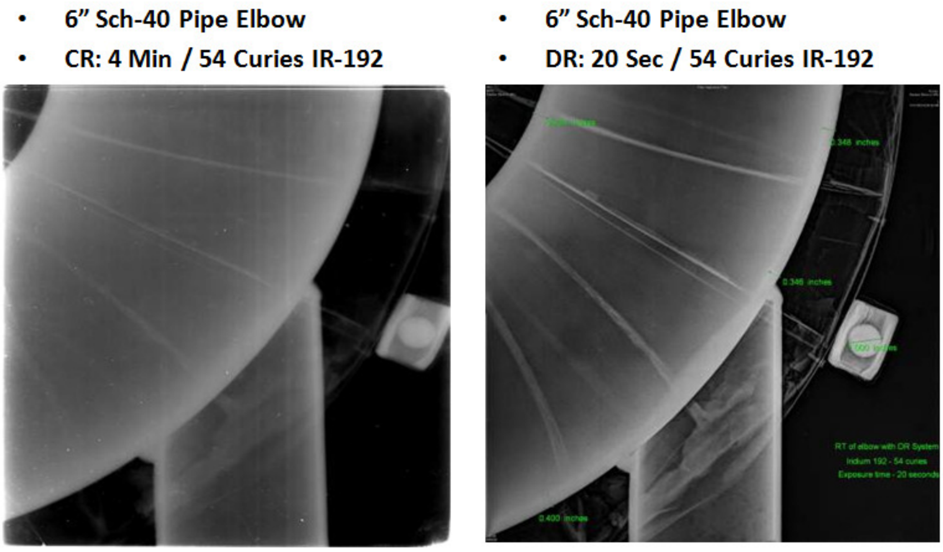

Figure 3 : Saving exposure time with Digital Radiography vs. Computed radiography

2.5. Codes and standards

The ASME code and the ISO/IIW communities have already recognized the importance of these new methods of inspection and have accepted these methods in the following references. The references to paragraphs included in the new CSA W59-13[4] have also been paraphrased below for reference.

2.6. Advanced Radiographic Inspection (ASME) code references[5]

a. Radiographic Examination using Computed Radiography in Accordance with ASME Section V, Article 2, appendix VIII can be applied to the radiographic examination of Vessels, tanks, boilers, power and petroleum piping.
b. The term film, as used in ASME Section V, Article 2 shall hereby refer to the phosphor imaging plates.
c. This technology can be applied to evaluate welds made in carbon and alloy steels, stainless steel and Inconel materials with a thickness range up to 10 inches using SE-75, IR-192, Co-60 or X-Ray up to 600KV
d. Acceptance standards of welds will be in accordance with ASME Section I, ASME Section VIII, Div 1, ASME Section IX for welder performance qualification, ASME B31.1 & ASME B31.1, API 650 as per 23.2.1 ASME Section VIII Div 1 UW-51 latest edition, ASME Section III, Division 1, to 2010 Edition latest addenda's.

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[4] Private communication from CSA W59 Technical Committee Secretary - Mr. Jeremy Fisher, e-mail: jeremy.fisher@csagroup.org

[5] Private communication form Mr. David Hebert, david.hebert@mistrasgroup.com

2.7. CSA W59-13 references

a. **ASTM E1255-09** :Fundamentally, radiography is an off-line, static examination technique, while radioscopy is a dynamic examination technique with the potential for on-line examination and process control. The new edition of the code recognizes radioscopy as an alternate radiation imaging system and refers to ASTM E1255-09, which describes the Standard Practice of Radioscopy.
b. **ASTM E2033 (2006)**: The new code also refers to this reference, which describes the Standard Practice for Computed Radiography (CR). A typical CR examination system consists of a radiation source, a storage phosphor imaging plate detector, a plate reader, an electronic imaging system, a digital image processor, a monitor display, a digital image achieving system, and, if desired, equipment for producing hard copy analogue images.

2.8. CSA W59-13 : Alternate radiation imaging systems Clause 8.1.6

The new code will now permit the use of ionizing radiation methods other than radiography on films, provided the selected method is agreed to in writing between the Engineer and the Contractor prior to the examination. The clause **8.1.6.1** includes techniques such as radioscopy, electronic imaging and real time radiography.

Clauses **8.1.6.4**, **8.1.6.5** and **8.1.6.6** describe the specifics of operator training requirements, the written procedures and establishment of essential variables to determine the required minimum sensitivity. Minimum sensitivity will be such that image seen on the monitoring equipment used for acceptance/rejection of welds per clause **8.1.4**, is not less than that required for radiographic film.

Clause **8.1.6.7** describes wire type and hole type IQIs and their selection and placement, while specifying that for in motion examination, two IQIs shall be positioned at each end of area of interest and tracked within the same run, without exceeding 3m (10) between each IQI.

Clause **8.1.6.9** requires the recording medium registering the results of the examination to be approved by the Engineer. **A written record shall be included with the recorded images** giving the following minimum information: identification and description of welds examined, procedure used, equipment used, location of the welds within the recorded medium and results, including a list of unacceptable welds and repairs, and their location within the recorded medium.

3. Description of Alternative Ultrasonic systems

Although welds can be evaluated using conventional ultrasonic techniques, which does not use toxic materials or radiation, this method is time consuming, the evaluation is often subjective and the raw data cannot be stored to be reviewed later, like the conventional radiographic technique. In case of dispute, another inspector is required to re-inspect the weld. The reports are made out on paper, and only the paper report is stored either physically or in an electronic format.

The base material being inspected must have isotropic sound properties with no internal discontinuities like laminations, large inclusions or porosity, which may hinder the propagation of sound on either side of the weld. Sound speed can change with the temperature. Hence, the temperature of the calibration block should be the same as the piece being inspected. For example, if the inspection is being performed on a bridge component in the winter time with a metal temperature of -20°C, the technician must carry a heavy calibration block to the site location and ensure that it is at the correct temperature prior to calibration and inspection.

The single angled conventional probes are limited in their ability to detect all the indications in a fixed position and hence the probe is swept back and forth perpendicular to the weld axis on each side of the weld to inspect the entire thickness of the weld. The probe then must be moved up along the axis of the weld and the process repeated to evaluate the entire weld length. The sound energy sent in the material being inspected will travel at difference speeds in different materials, requiring matched calibration blocks for the material being inspected. To couple the sound energy to the material being inspected, a coupling agent like glycerine is often used between the sound probe and the material being inspected. In addition, the entire scanning zone on either side of the weld must be ground to adequate smoothness to minimize the loss of signal at contact. Grinding is another non-value added operation. This zone increases with increasing thickness of weld being examined.

Alternative ultrasonic methods provide solutions to some of the problems mentioned above, and in particular avoid the need to grind large width of material on either side of the weld joint. A brief description follows.

3.1. Phased Array Ultrasonics

Phased array ultrasonic technique (PA) or (PAUT), is an advanced method of ultrasonic testing that has applications in industrial non-destructive testing. Common applications are to non-destructively find flaws in manufactured materials such as welds. Single-element (non-phased array) probes, known technically as monolithic probes, emit a beam in a fixed direction.

To test or interrogate a large volume of material, a conventional probe must be physically scanned (moved or turned) to sweep the beam through the area of interest. In contrast, the beam from a phased array probe can be moved electronically, without moving the probe, and can be swept through a wide volume of material at high speed. The beam is controllable because a phased array probe is made up of multiple small elements, each of which can be pulsed individually at a computer-calculated timing. The term phased refers to the timing, and the term array refers to the multiple elements.

3.2. Probes

In comparison to conventional ultrasonic inspection, where either there is only single element in the probe that does the entire job of sending the sound signal into material and then receiving it back or a probe consisting of one signal generator and one receiver, in phased array system the probe could consist from 16 to 256 elements. (Fig.4)

Figure 4 Conventional UT AWS Snail wedge probe & Phased Array probe courtesy Olympus

The number of elements in the probe depends upon the required focusing area. If area to be covered is more, number of elements should be more as increase in elements will also increase focusing and steering capability of probe. To increase the beam steering capability, the width of element should be reduced. But on other hand, this will require more number of elements to cover a wider area.

3.3. Wedges

In most cases, PAUT probes are used with plastic wedges. (Fig.5). Wedges help in converting or refracting the sound signals at desired angle. They also protect the probes from rough metal surface. A conventional UT inspection requires a number of different transducers. A single phased array probe can be made to sequentially produce the various angles and focal points required by the application.

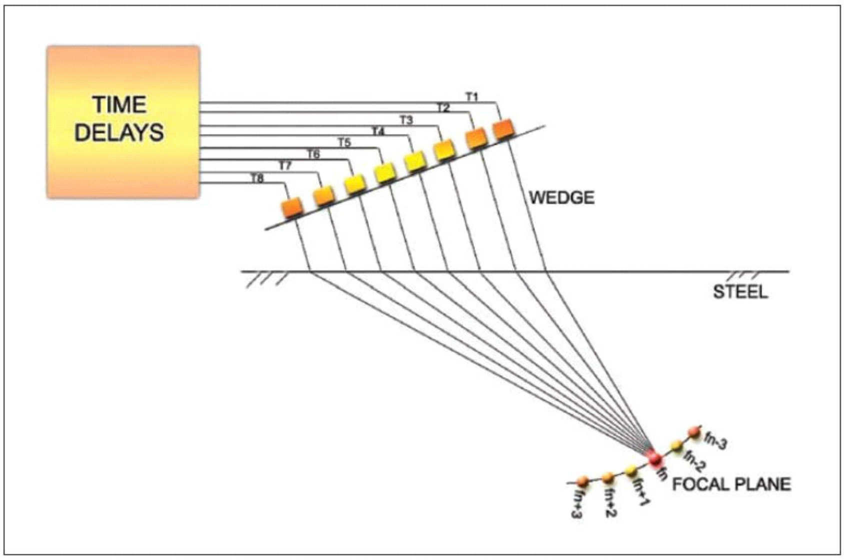

Figure 5 Conceptual illustration of the phased array principle. Time delays to the eight elements control focusing and beam sweep.

3.4. The computer system and software

To generate a beam, the various probe elements are pulsed at slightly different times. By precisely controlling the delays between the probe elements, beams of various angles, focal distances, and focal spot sizes can be produced. The echo from the desired focal point hits the various probe elements with a computable time shift. The signals received at each probe element are time-shifted before being summed together. The resulting sum is an A-scan emphasizing the response from the desired focal point and attenuating various other echoes from other points in the material. A scan plan is shown in Fig. 6.

Manual Phased Array Ultrasonic Technique for Weld Application is described by Anandamurugan[6] for reference.

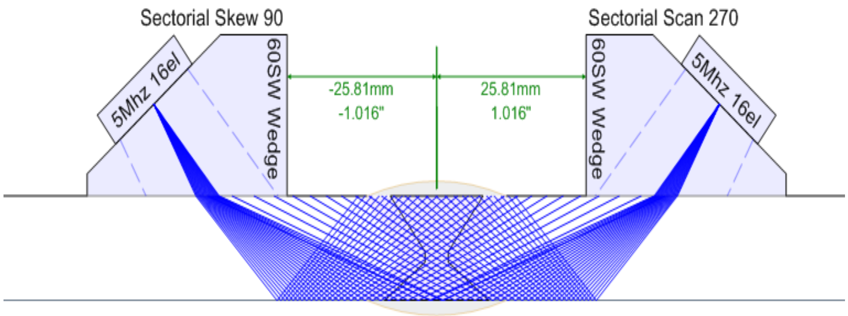

Figure 6 Phased array scan plan for a butt weld

3.5. Time of Flight Diffraction

The time of flight diffraction (TOFD) techniques are used primarily for detection and sizing the depth of crack-like flaws. When an ultrasonic beam interacts with a crack-like flaw, the major amount of its energy reflects and possibly, mode converts, according to well-known laws. In the vicinity of sharp crack tips, a small portion of energy radiates in the form of diffracted waves. This diffracted energy is converted to flaw sizing.

In a TOFD system, a pair of ultrasonic probes sit on opposite sides of a weld. One of the probes, the transmitter, emits an ultrasonic pulse that is picked up by the probe on the other side, the receiver. In sound material, the signals picked up by the receiver probe are from two waves: one that travels along the surface and one that reflects off the far wall. When a crack is present, there is a diffraction of the ultrasonic wave from the tip(s) of the crack. Using the measured time of flight of the pulse, the depth of a crack tip can be calculated automatically by simple trigonometry. (Fig.7). This method is even more reliable than traditional radiographic, pulse echo manual and automated weld testing methods.

[6] Manual Phased Array Technique for weld application :http://www.ndt.net/article/nde-india2009/pdf/12-A-2.pdf

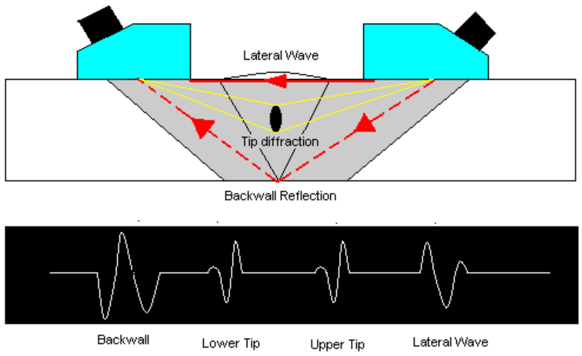

Figure 7 TOFD set up with transmitting and receiving probes, yellow traces are diffracted from the flaw

TOFD is a powerful technique, allowing efficient and fast inspection along with very accurate sizing of flaws. TOFD is an amplitude-independent flaw sizing method, providing excellent sizing even in the presence of noise. This technique has many advantages and some disadvantages

- Wide coverage area using a pair of transducers with on-line volume inspection and very fast scanning
- Accurate flaw sizing; amplitude-independent
- Unlike Phased Array inspection, TOFD does not need the exact weld configuration
- Very sensitive to all kinds of defects
- No sensitivity to defect orientation
- TOFD suffers from a dead zone near the surface and the back wall.
- A secondary inspection of both surfaces either with UT or Phased array is recommended (Fig.8)

TOFD is used for inspecting butt welds in flat plates and cylindrical objects. It is a rapid technique and often used for fracture toughness assessments for fitness for purpose calculations.

Figure 8 Olympus OmniScan MX-2 with weld rover scanner PA + TOFD

3.6. ASME, AWS and CSA code references for Alternate Ultrasonic systems

a. Use of Ultrasonic Examination in Lieu of Radiography can be performed using the ASME code case 2235-9 per the ASME Section V, Article 4, appendix III for ASME section I, Section VIII Div 1 & 2 and Section XII (Transport by ground, air, sea of dangerous good by tanks)
b. Advanced Ultrasonic Examination using Phased Array sectorial scans or Time of flight Diffraction can be applied to carbon and alloy steels using the code cases 2235-9 and Code Case 2557 which covers manual Phased array examination.
c. The code case provides guidance for qualification of procedure, equipment and personnel qualifications, with flaw acceptance criteria for weld thicknesses of 0.5"to 1";1.0" to 12 inches and welds greater than 12" thick.
d. The code case for pressure piping B31 181, describes use of Alternative Ultrasonic Examination and acceptance criteria using the phased array method (Jan 2007)
e. UT Examination of Welds by Alternative Techniques - Annex S (informative) is not part of the AWS D1.1/D1.1M:2008 Structural welding Code - Steel. The purpose of this annex is to describe alternative techniques for UT of welds. The techniques described are proven methods currently being used for other application but not presently detailed in the code. The alternative techniques presented require qualified, written procedures, special UT operator qualifications and special calibration methods needed to obtain the required accuracy in discontinuity sizing. The use of this annex and the resulting procedures, including the applicable acceptance criteria are subject to approval by the Engineer.
f. Use of Phased Array automated systems for pipelines - API and CSA Z662 standards.

3.7. Inspector qualifications and training for Alternate Ultrasonic systems

There are various training methods available to certify inspectors to Phased Array and TOFD methods. As the new CSA W59-13 standard is implemented, NRCAN at CGSB is looking into expanding the certification to these new methods. The following references are currently available outside of the CSA W59-13:

a. ASNT SNT-TC-1A or CP-189 is an American Society for Non destructive testing standard for qualification and certification of Non-destructive Testing Personnel. The ASME code cases referred to above, require the personnel to be qualified and certified in accordance with their employer's written practice. Only Level II or III personnel shall analyse the data and interpret the results. In addition, personnel who acquire and analyse UT data shall be trained using the equipment and must demonstrate that they are able to set up and evaluate discontinuities on a demonstration piece. This is an internal certification.

b. Training and Certification Scheme for Weld Inspection Personnel (CSWIP) promoted through TWI, UK is a third party certification scheme, more in line with CSA standards philosophy. Phased Array and TOFD training and certification to EN ISO 9712:2012 TWI has now extended its certified methods to include the advanced UT methods.

c. From past experience of Mistras Metaltec Inc., the recommended training hours for a level II CGSB UT inspector is at least 80 hours of training with the advanced UT equipment, calibration block and demonstration pieces for developing the needed skills to perform phased array inspection on a specific application.[7]

3.8. CSA W59-13 references

a. ASTM E2373-09 : Standard Practice for the use of TOFD technique
b. ASTM E2700 : Standard Practice for contact ultrasonic testing of welds using Phased Arrays

3.9. CSA W59-13 : Alternative Ultrasonic systems - Clause 8.2.12

The acronym **AUT** is used in many different ways. It has been used for *automated ultrasonic testing* in the past, using conventional UT probes and some others use it for *advanced ultrasonic testing to include PA and TOFD.* After much debate, the CSA W59-13 technical committee chose the term Alternative Ultrasonic systems to include all the variety of systems outlined in the clause **8.2.12.1**. The clause further stipulates that Alternative Ultrasonic Systems may only be used if agreed to in writing by the Engineer and the Contractor prior to the examination.

8.2.12.2 clause provides for Inspection personnel shall be qualified to CAN/CGSB-48.9712/ISO 9712 for conventional UT and, in addition, shall have completed a level 2 or 3 training program specific to the ultrasonic system used. A level 3 inspector with specific UT training shall approve the inspection procedures.

8.2.12.3 and 8.2.12.4 deal with the inspection procedure documentation including what must be included in the report including the method of verifying the accuracy of the completed examination. This verification may be made by a re-UT by others (audit) or other NDE or destructive methods accepted by the Engineer. All records must be retained for a predetermined negotiated period of time after the completion of the examination.

8.2.12.5 covers the qualification of the procedure to ensure it will provide the required sensitivity of the inspection technique, while identifying all the essential variables and combinations thereof. The results of the qualification shall be recorded in the same medium that is to be used for production examination.

8.2.12.6 is an important clause that provides a minimum acceptance criteria.

a. for semiautomatic or automated alternate UT, thereby meaning scans which are encoded, the acceptance criteria will be the same as the Radiography Clause 8.1.4 for static and cyclically loaded structures or acceptance criteria demonstrated to be equivalent.
b. For manual alternate UT is referred to the ultrasonic acceptance criteria for statically or cyclically loaded structures or acceptance criteria demonstrated to be equivalent.11.5.4.5 or 12.5.4.5.

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[7] "Pushing the boundaries with Phased Array UT Inspection" (Boiler Tubes) V.Vaidya et al CINDE conference 2012

4. R&D to produce demonstration plates

A R&D program was launched at Mistras-Metaltec to create demonstration plates in various thicknesses with real defects. The initial funding came from Mistras-Metaltec to buy the required steel materials. Welds in Plates 0.5", 0.75" and 1.5" were targeted in the first part of the program. Most of the work done for this development has been in kind from various collaborators and more cash funding and help will be needed to extend the work to cover higher thicknesses.

In order to produce real cracks on demand, the author with the help of Technical staff at ESAB[8] designed a special FCAW wire, such that under restraint the wire would produce cracking due to the higher levels of Boron, added to a base chemistry of a standard CSA E491T-9C or E71T-1C type wire. This was designed to produce a chemistry close to the C-Mn base metal of CSA 300W for the plates.

Jocelyn Bergeron[9] from Structal- Canam helped with the butt welding of plates and provided a welder to experiment with the development of cracking in the desired locations. The butt welds were first welded with SAW process to first clear RT examination and then the plates were gouged from one side to introduce the desired defects, as shown in the figure 9.

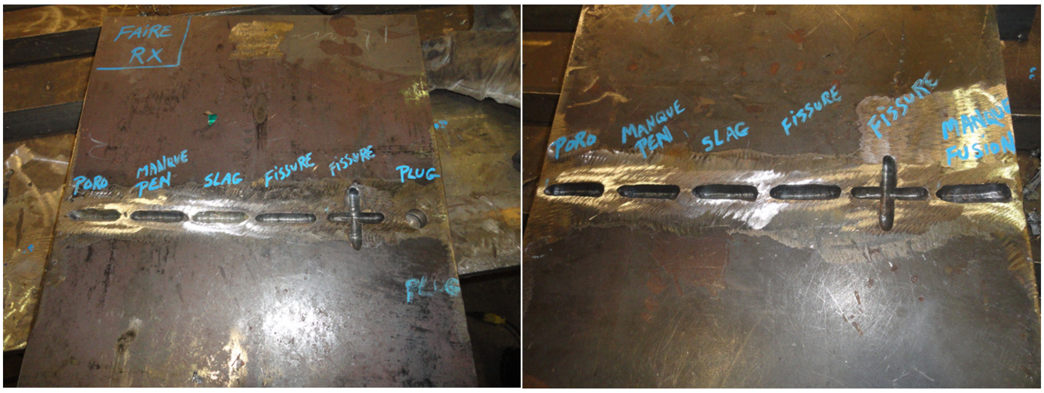

Figure 9 : 300W test plates 24" x 18" & 0.75" and 1.5" thick from left to right, with gouged cavities to introduce real defects, porosity, lack of fusion, slag, crack, crack and crater crack in a plug weld or lack of fusion respectively.

After filling the deep narrow groove with special Ti-B wire, magnetic particle inspection was conducted to verify if cracks were indeed present in the thickness. Magnetic particle inspection confirmed the presence cracks.(Fig. 10).

Creation of cracks with the Ti-B FCAW wire was related to restraint in the joint. We could not produce cracks open to surface as we hoped, but they were present in the 1.5"thick plates. On the contrary, we could not produce cracking on demand in the 0.5" thick material and 0.75" thick plate, due to lack of sufficient restraint. A plug weld in the 0.75" thick plate produced crater cracking.

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[8] Private communication with Mr. Stan Ferree at ESAB e-mail: SFerree@esab.com
[9] Private communication with Mr. Jocelyn Bergeron, e-mail : jocelyn.bergeron@canam.ws

Figure 10 Magnetic particle tests to confirm presence of cracking

4.1. Demonstration pieces for advanced inspection comparison

It should be noted that large test plates 18" x 24" were selected for this project to facilitate encoded scanning while using advanced ultrasonic methods like PAUT and TOFD. The scanner thus could be moved across both the plates, while providing sufficient parking areas for the scanner on 1.5 inch thick wood support to match the 1.5" thick test plate. Since the plates are heavy and difficult to manipulate, an electric height adjusting portable table was provided by Techno Vogue Inc., for this purpose. The table top surface 27" x 72" has openings so that radiographic inspection can also be done easily without removing the plates while adjusting the table height accordingly. (Fig. 11).

Figure 11 Test plates and calibration test blocks with an electric height adjustable mobile table for ergonomy

5. Inspection of test plates with Computed Radiography (CR)

The plates were welded up with a regular CSA E491T-9C wire to produce the other planned defects. The test plates were then inspected with standard radiographic technique at CANAM to confirm the presence of flaws at the desired locations. The test plates were then re- inspected with the Computed Radiography (CR) technique at Mistras-Metaltec under the supervision of Mr. David Hebert. The CR testing was quick and straight forward.

6. Inspection of test plates with PAUT

The test plates were inspected with standard UT procedure at Mistras-Metaltec and then the plates were shipped to Olympus Labs for further evaluation. Dr. Michael Moles[10] provided invaluable help to the author to arrange for the laboratory facilities and feedback with respect to most recent developments at AWS and IIW with respect to calibration blocks to be used for Phased Array inspection for structural work. Mr. Richard Rheaume[11], President of Phasex Inc offered his time and help to complete the preliminary testing of the test plates with Phased Array.

Mr. Richard Rheaume a ASNT level 3 expert has many of experience in developing and using the Phased Array technology and had developed a special calibration block for inspecting a major bridge in Venezuela using a specifically designed calibration block for structural work. His invaluable help steered the project in the right direction.

6.1. Calibration block design

It is important to calibrate the phased array before using it for inspection. Since, PA has many elements in the probe, it becomes very important to normalize the response from each focal law, varying wedge attenuation and sensitivity variation among elements. Calibration makes sure that inspection will give clear imaging and accurate positioning and sizing of indications.

Since there are no guidelines in CSA W59-13 for Phased Array ultrasonic technique, the non-mandatory ANNEX S of AWS D1.1/D1.1M:2008 was used as a guide. The Annex S provides a general guideline for designing calibration blocks. Mr. Richard Rheaume recommended a design based on his many years of practical experience using these guidelines: His recommendations are:

- 6.1.1. Calibration block must be large enough to accommodate the probe with carbides.
- 6.1.2. Precision positioning of the holes (SHD) is very important.
- 6.1.3. The calibration holes must be well away from the corners so the corner signal doesn't interfere with the TCG calibration.
- 6.1.4. TCG Calibration must be done at a 50% reference level so the +5 dB is still below 100% FSH and the indications can be properly evaluated.
- 6.1.5. No additional dB must be added for scanning as it would push many indication amplitude above 100% and they cannot be properly evaluated (OmniScan and other instruments only record until 100% FSH, anything above is seen as 100% and it cannot be lower with the software for analysis)
- 6.1.6. Use of Annex S is recommended for PAUT because the normal table restricts the range of angle from 45 to 70. With PAUT it is very common to go from 34 to 72 degree. Annex S doesn't restrict the range of angles

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[10] Private communication with Dr. Michael Moles, e-mail: Michael.Moles@olympusndt.com

[11] PAUT expert and sponsor Phasex Inc, Mr. Richard Rheaume, e-mail: level3software@hotmail.com

6.1.7. Annex S permits the use of a transducer of minimum 0.25" size of any shape and a frequency up to 6 MHz.

6.2. Manufacturing of the calibration block

It took a long time to create the desired calibration block, due to the accuracy needed in preparing it. Since a multi-element compact probe is to be used for PAUT, focal laws for each element must be evaluated and corrected for proper evaluation. If the block is not perfectly square or the holes are not drilled perfectly parallel and perpendicular to surfaces of the test block, or the sizing of the holes is not accurate, then the TCG can take a very long time or may not be possible. The required tolerances for preparing the calibration block were specified as below:

- Calibration block must be square
- SHD dimensional tolerance should be 1.50mm ± 0.05 mm or 3.00±0.05 mm
- Tolerance for positioning of the SHD in the thickness should be ± 0.02 mm
- Overall calibration block dimensions were 700 ±0.2 mm by 38±0.2 mm by 70±0.2 mm

Four blocks of 300W material were laser cut from the same heat of 1.5" thick plate for trial machining. The calibration block was prepared from the same heat of plate used for preparing the demonstration pieces. Due to the required 38 mm thickness of the block conventional drilling or 1.5mm diameter hole was not possible to the required tolerances. Richard Rhéaume had procured a test block for the overseas project from a machine shop in Italy, but this was not an option due to cost and time delays. Mr. Jasdeep Ratol from Concordia University contributed to the successful production of the required calibration block.

Several machine shops were contacted for accuracy of machining. Two alternatives were retained.

- Preparing the calibration block by using water jet cutting technology[12] and then finish machining[13] the outside of the block and the holes to final dimensional tolerance. These tests were successful, however the minimum SHD dimension achieved by this method was 3 mm dia.
- Preparing the required calibration holes 1.50mm±0.05 mm with Electro Discharge Machining (EDM)[14] and finish machining the test block to required dimensions.

The EDM test block was found to be acceptable for the 1.5 mm SHD sensitivity, as required by the Annex S of AWS D1.1 code. Figures 12 & 13 show the details of the proposed calibration block for structural inspection using the PAUT system.

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[12] Rejean Caouette - Water Jet cutting , e-mail: r.caouette@crccanada.net
[13] Dhillon Machine shop - Varinder Dhillon, e-mail: info@dhillonmachineshop.com
[14] Eli metal Inc - EDM machining, Pierre Sicotte : www.elimetal.com

Figure 12 Calibration block in CSA 300W material 700mm long by 38mm thick by 70mm high, four (4) - 1.5mm SHD & one(1) - 3mm SHD, use a straight edge along the length for probe stability while performing TCG calibration

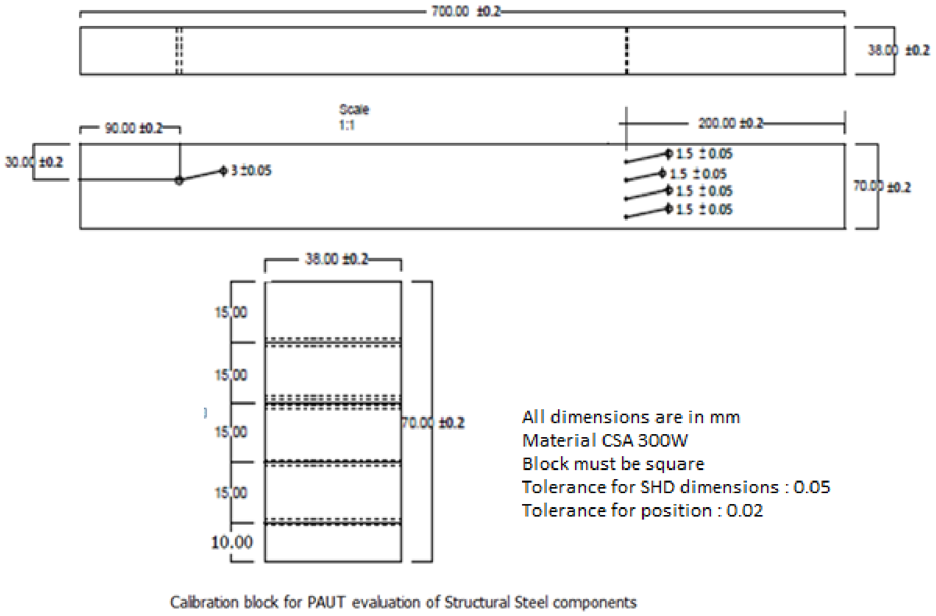

Figure 13 Calibration Block for Phased Array evaluation based on AWS D1.1 Annex S

6.3. Time Corrected Gain[15]

For sizing defects, A-scan amplitude techniques using DAC curves or time corrected gain are common. These methods account for material attenuation effects and beam spreading by compensating gain levels (TCG) or drawing a reference curve based on same size reflector response as a function of distance. As in sensitivity calibrations, some instruments allows a TCG to be built at multiple points over all defined focal laws. In these instruments, the view can be switched from TCG to DAC curve at any time. This allows use of sizing curves at multiple angles for sectorial scans or at any virtual aperture in linear scans.

As beam formation relies on variant element delays and groups, it is important to normalize the response from each focal law, to compensate both for element-to-element sensitivity variations in the array transducer and for varying wedge attenuation and energy transfer efficiency at different refracted angles. Calibration of wedge delay and sensitivity over the entire inspection sequence not only provides clearer image visualization, but also allows measurement and sizing from any focal law.

[15] http://www.olympus-ims.com/en/ndt-tutorials/calibration/calibrationnormalization/

Mr. Stephan Couture[16] of Olympus graciously supplied the required equipment for evaluation of the demonstration pieces. The equipment used for the evaluation was: (Fig.14)

- OmniScan MX2.
- The phased array probe 5L60 A14. This is a Standard Phased Array Probe, 5 MHz Linear Array, 60 Elements, 60x10 mm Total Active Aperture, 1.00 mm Pitch, 10 mm Elevation, A14 Case Type, 68mm length by 28mm width by 20 mm height.
- Wedge SA14 N55S. This is a standard wedge for angle beam phased-array probe A14, normal scan, 55° shear wave, plain wedge (without irrigation holes and carbides).
- Scanner: Olympus PV100 or equivalent

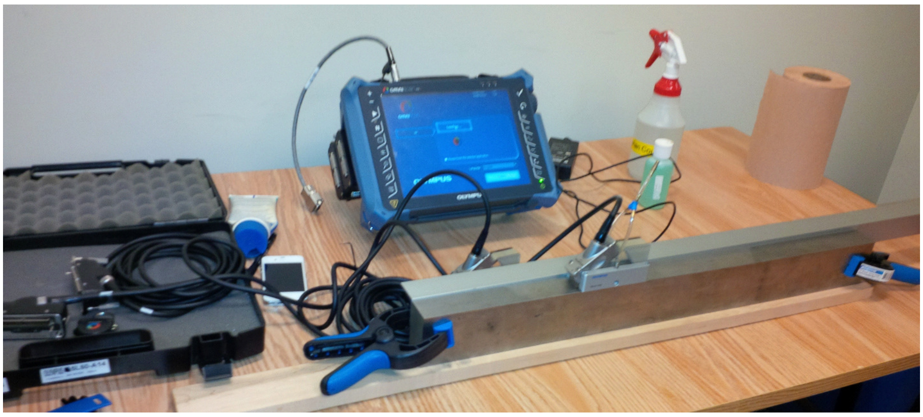

Figure 14 Set-up for TCG Calibration of the 16 element 5 MHz probe Olympus 5L60 A14

The scanning was encoded and the data was analysed to Acceptance-Rejection criteria from ANNEX-S table S.1. Additional work will be required in this area to understand how this will compare to acceptance criteria stipulated in the new CSA W59-13 clause 8.2.12.6. The annex S table S.1 is reproduced below for reference.(Fig.15)

[16] Stephan Couture - Olympus-ndt, e-mail: stephan.couture@olympusndt.com

ANNEX S AWS D1.1/D1.1M:2008

Table S.1
Acceptance-Rejection Criteria (see S12.1)

Maximum Discontinuity Amplitude Level Obtained	Maximum Discontinuity Lengths by Weld Classes			
	Statically Loaded	Cyclically Loaded	Tubular Class R	Tubular Class X
Level 1—Equal to or greater than SSL (see S6.1 and Figure S.14)	> 5 dB above SSL = none allowed 0 thru 5 dB above SSL = 3/4 in [20 mm]	> 5 dB above SSL = none allowed 0 thru 5 dB above SSL = 1/2 in [12 mm]	See Figure 6.4	See Figure 6.5 (Utilizes height)
Level 2—Between the SSL and the DRL (see Figure S.14)	2 in [50 mm]	Middle 1/2 of weld = 2 in [50 mm] Top & bottom 1/4 of weld = 3/4 in [20 mm]	See Figure 6.4	See Figure 6.5 (Utilizes height)
Level 3—Equal to or less than the DRL (see Figure S.14)	Disregard (when specified by the Engineer, record for information)			

Figure 15 AWS Annex S, table S.1

6.4. Results of the experimental development

The experimental tests were able to produce the desired weld defects in the identified locations. The production of cracking with the special Ti-B FCAW wire worked well with thicker plates. Only Computed Radiography (CR) and Phased Array ultrasonic testing (PAUT) was completed. The results are self explanatory in figures 16 and 17.
Cluster porosity, lack of penetration, slag, cracks and crater cracks were confirmed to be present by both CR and PAUT techniques while using an encoded scan. The data for both the techniques is stored on electronic media for further reference.

6.5. Discussion for Quality Engineering

Looking back at the proposed new technologies and the time it took to use some on them on the experimental demonstration pieces, it can be observed that the CR technique was relatively simple to implement with no real issues. The documentation of the CR results on a DVD was easy, however a program was needed to open the files to review the data. Apart from that, the images were far clearer than the conventional film images, with the added benefit of electronic tweaking of the image data.

PAUT on the other hand was quite involved requiring the availability of a level 3 experienced expert like Mr. Richard Rheaume to support and guide the development. The machining of the required type of calibration block took time and fortunately, the final machining of the calibration block was of excellent quality. The TCG calibration took several hours to complete and evaluation of the test pieces was completed the following day. The test plates were etched on the ends, to show the type of joint geometry that was used for the butt welding of the plates. This information was essential for the PAUT set up for the encoded and S-Scans. Further, the plates were ground flush and there was no weld reinforcement left on the test pieces. This simplified the PAUT evaluation. Excessive weld reinforcement widths on butt welds and root reinforcements or concavities on one sided welds can complicate PAUT evaluation.

In comparative terms based on this limited experimental testing, CR application was much simpler than application of PAUT. In practice, where Radiography cannot be used, the execution of PAUT is faster than conventional UT following approximately the 80/20 rule. It takes more time to set up the PAUT testing protocol than conventional UT and it takes far less time to perform the actual evaluation using PAUT compared to the conventional UT, respectively. For these reasons, contractors wishing to use PAUT need advanced notice and good planning for its successful implementation.

No attempt has been made to evaluate the demonstration test plates with a DR system, nor any attempt made to scan the plates with TOFD to detect and size the indications.

7. Conclusions and comments

7.1. This paper describes the new technologies for inspection that will be included in the new CSA W59-13 code. It is hoped that the experimental testing conducted so far will provide a guidance for the selection of these new technologies for production work.

7.2. A description of the new clauses in CSA W59-13 related to advanced non destructive testing are included with many technical references from other codes for bench marking

7.3. The preliminary results of this comparative analysis of indications using conventional UT, RT and alternate radiation ionization systems and alternative ultrasonic systems show a good correlation.

7.4. As the AWS, IIW code committees deliberate to discover a design for a calibration block, this experimental work recommends a calibration block for PAUT that facilitates the TCG calibration of probes containing 16 or more elements with ease. It is hoped that this work will provide some guidance to a potential fabricator and Engineer with some alternatives.

7.5. The experimentally produced demonstration pieces are supported on an electric table to facilitate radiography and encoded scans on the large size specimens. Currently the demonstration system is at CINDE labs[17] for evaluation courtesy of Techno Vogue Inc. for evaluation of technologies.

7.6. Additional work is required to compare the PAUT results to CR results with respect to the acceptance criteria stipulated in the new CSA W59-13 clause 8.2.12.6.

7.7. Additional work is needed to complete the evaluation of DR and TOFD on the demonstration plates and sponsors are solicited.

7.8. Anyone interested to experiment with the demonstration test plates, please contact the principal author.

[17] CINDE, Doug Whitley for evaluation of demonstration pieces-Oct 2013 e-mail: D.Whitely@cinde.ca

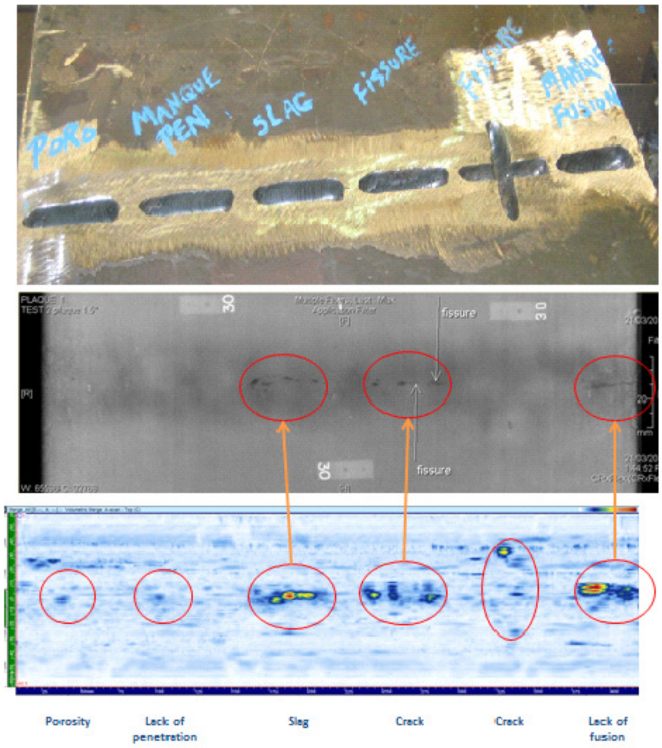

Figure 16 Comparison of PAUT results of 1.5'' thick plate with Computed Radiography and test plan for defects

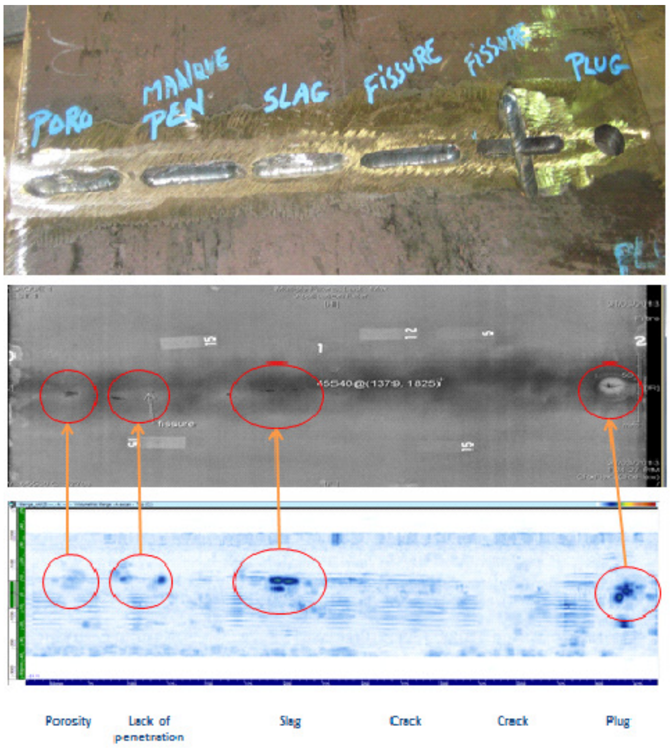

Figure 17 Comparison of PAUT results on 0.75'' thick plate with Computed Radiography and the test plan for defects

8. Acknowledgments

The principal author wishes to thank all the sponsors for this project: Mistras-Metaltec, ESAB Canada, NRCan, CWB Group, Phasex Inc, Mistras-Metalec Inc, Structal-Canam, Hydro Coupe, Omniweld, Concordia University. Elimetal Inc and Dhillon Machine Shop in Ville St. Laurent. Special thanks are due to Olympus - NDT division and Phasex Inc., for providing the equipment, laboratory space and know-how for testing alternative Ultrasonic Inspection systems.

References

1. Youtube video - DR : http://www.ge-mcs.com/en/radiography-x-ray/digital-x-ray/dxr250c-w.html
2. Private communication with Mr. Marc Turmel, ing marc.turmel@mistrasgroup.com
3. 17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China entitled 'Digital radiography and Computed radiography for Enhancing the Quality and Productivity of Weldments in Boiler components' by R.J. PARDIKAR, SDGM / NDT, BHEL, Tiruchirappalli,Tamilnadu-620014. Tel:+91-431-2575237,Fax:+91-431-2520730. e-mail:rjp@bheltry.co.in
4. Private communication from CSA W59 Technical Committee Secretary - Mr. Jeremy Fisher, e-mail: jeremy.fisher@csagroup.org
5. Private communication form Mr. David Hebert, david.hebert@mistrasgroup.com
6. Manual Phased Array Technique for weld application :http://www.ndt.net/article/nde-india2009/pdf/12-A-2.pdf
7. "Pushing the boundaries with Phased Array UT Inspection" (Boiler Tubes) V.Vaidya et al CINDE conference 2012
8. Private communication with Mr. Stan Ferree at ESAB e-mail: SFerree@esab.com
9. Private communication with Mr. Jocelyn Bergeron, e-mail : jocelyn.bergeron@canam.ws
10. Private communication with Dr. Michael Moles, e-mail: Michael.Moles@olympusndt.com
11. PAUT expert and sponsor Phasex Inc, Mr. Richard Rheaume, e-mail: level3software@hotmail.com
12. Rejean Caouette - Water Jet cutting , e-mail: r.caouette@crccanada.net
13. Dhillon Machine shop - Varinder Dhillon, e-mail: info@dhillonmachineshop.com
14. Eli metal Inc - EDM machining, Pierre Sicotte : www.elimetal.com
15. http://www.olympus-ims.com/en/ndt-tutorials/calibration/calibrationnormalization/
16. Stephan Couture - Olympus-ndt, e-mail: stephan.couture@olympusndt.com
17. CINDE, Doug Whitley for evaluation of demonstration pieces-Oct 2013 e-mail: D.Whitely@cinde.ca