A Practical Application of Phased Array Inspection at High Temperature

Larry ETHERINGTON[1], Alistair MacRAILD[2]

[1]Eclipse Scientific Inc.
97 Randall Drive, Waterloo ON, Canada, N2V 1C5
(800) 490-1072; fax (519) 886-1102; e-mail: letherington@eclipsescientific.com

[2]ALS Global
Unit 1/2 Alhambra Avenue, Cardiff NSW 2285, Australia
+61 2 4953 7999; fax +61 2 4954 9939; e-mail: Alistair.MacRaild@alsglobal.com

ABSTRACT

This paper investigates the practical challenges of the application of ultrasonic inspection of Engineered Material Components (EMC) at elevated temperatures. ESBeamTool HighTemp is a visualization tool indicating the relative temperature changes within the Phased Array (HTPAUT) wedge as it relates to high temperature material evaluation. The variations in the wedge must be taken into account. It is these wedge temperature variations, which dictate the ultrasonic beam exit point at the material interface, producing predictable material inspection angles according to Snell's law.

Keywords: Phased Array, ESBeamTool High Temp, Practical Application Phased Array at High Temp

Introduction

The cost benefit to monitoring detrimental flaws without having to shut systems down is becoming a very attractive methodology. The option for High Temperature Phased Array Inspection (HTPAUT) has been developed and shows a good correlation between inspection at ambient temperatures and high temperature inspections.

Eclipse Scientific Inc. has recently introduced the development of a high temperature HTPAUT inspection system, ESTempMaster. The ESTempMaster, features a wedge material capable of 100% duty cycle to temperatures up to 350^{o} Celsius and a radiator like water jacket to maintain a safe transducer operating temperature. (See Figure 1.)

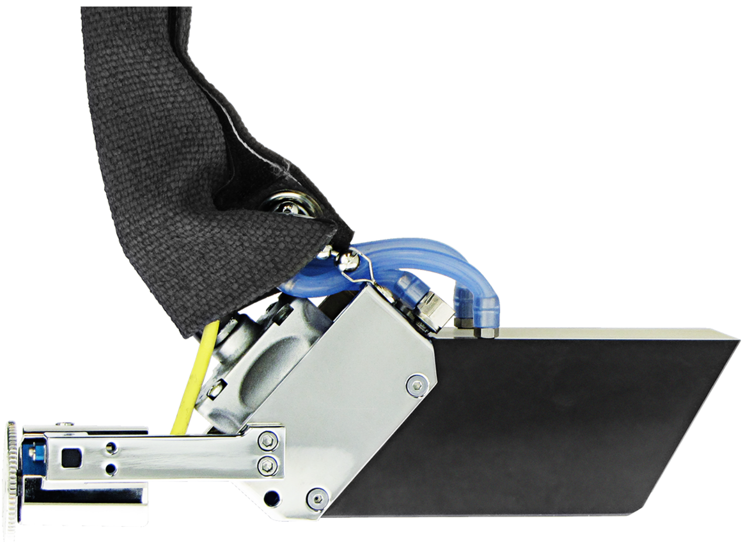

Figure 1: ESTempMaster WA12 and Probe Protection System

High Temperature Inspection Challenges

At normal or ambient temperatures, EMC materials such as carbon steel are isotropic with respect to velocity of ultrasonic waves. As the temperature in the inspection material (steel) increases, the sound velocity decreases and the inspection angle decreases.

In addition, the temperature effect on the wedge must be considered, as the incident angle into the inspection medium must be realized. The temperature affects the wedge in gradients and is therefore virtual and based on active apertures selection.

The challenge in the practical application of technique development is a realization of the intended volumetric coverage (normal temperature) vs. volumetric coverage (at elevated temperature).

The location and the incident angle of the beam at the wedge to material interface is altered, due to the wedge temperature gradient. (See Figure 2.)

The migration in the incident angle translates to a potential shift in flaw location displayed on the phased array instrument in both the index offset and depth perception. This inaccurate index and depth perception is variable due to the virtual apertures, wedge temperature/velocity gradient, and inspection part temperature/velocity. (See Figure 3.)

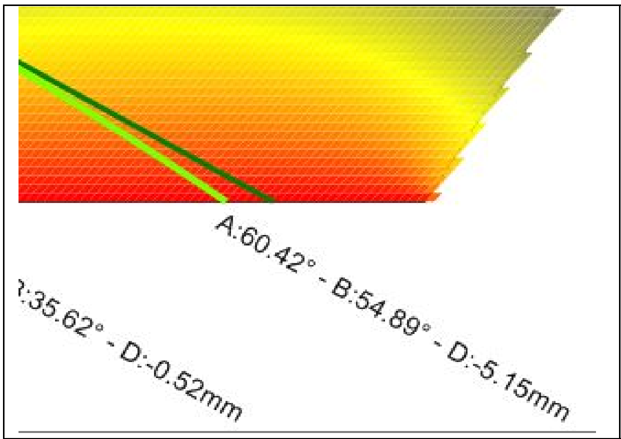

Figure 2: Incident Angle Beam Migration

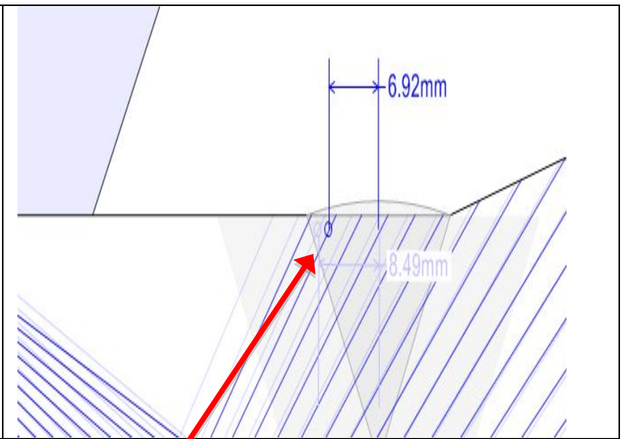

Figure 3: Flaw Location Shift in Index Perception

ESBeamTool6 High Temperature Utility

In conjunction with the development of the ESTempMaster probe protection system, Eclipse Scientific Inc. added a high temperature visualization utility to ESBeamTool6. The high temperature visualization utility provides for the beam correction paths based on the chosen apertures, ambient temperature, wedge gradient, material temperature and the delta affects applied to sound velocity and most importantly corrected beam angle. The ESBeamTool6 HighTemp Visualization Utility is depicted in (See Figure 4.)

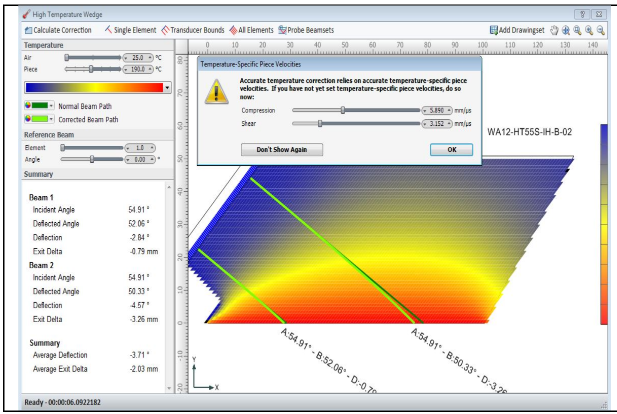

Figure 4: ESBeamTool6 High Temp Visualization Utility

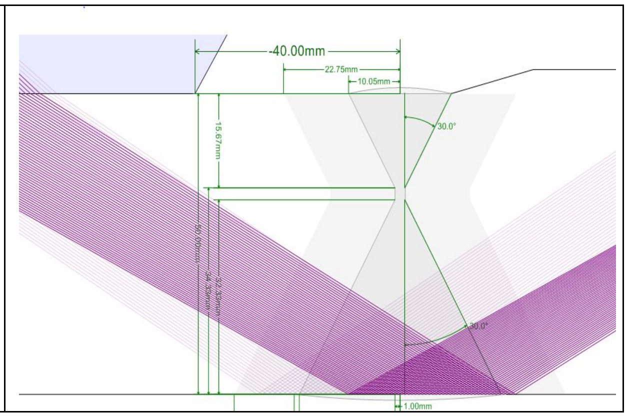

Figure 5: Ultrasonic Beam Correction in Steel

Practical Application - High Temperature Inspection

The practical application of Eclipse Scientific Inc.'s high temperature solution was carried out in 2015 on the shell to the head of an in-service pressure vessel operating at approximately 190° C. A previous comprehensive offline phased array inspection at ambient temperature was carried out in 2014. The 2014 inspection revealed significant defects and the goal of the re-inspection was to conduct a comparison to monitor potential growth of any previously reported defects.

Test Limitations

Scanning was carried out from the external surfaces of the vessel shell where there were scan access restrictions at locations due to nozzles and attachments which limited access for scanning.

The scanning surface was wire buffed and wiped clean of loose debris but some tightly adherent scale still remained on the scanning surface. The surface was also slightly undulating and significant grinding divots were caused from the removal of insulating support rings which caused issues with the effectiveness of probe coupling. The internal weld cap surface geometry resulted in PAUT signal responses from the stringer bead welding peaks and valleys. These signal indications could mask near surface in-service defects, which are difficult to interpret at long beam path lengths. It is recommended that light dressing and magnetic particle inspection of the internal and external weld cap is to be completed to ensure the integrity of the weld in this region.

Table 1: Test Parameters

Material Specification: Low Alloy Carbon Steel		Surface Preparation: Buffed
Surface Condition: As welded/tightly adherent scale/ grinding divots		
Ultrasonic Instrument	OmniScan MX2	32:128
	Group 1	**Group 2**
Probe	5L64-A12-P-10-OM	5L64-A12-P-10-OM
Serial/ID	ESP001690	ESP001690
Array Type	1D Linear Array	1D Linear Array
Wedge	ESTempMaster-WA12-N55S	ESTempMaster-WA12-N55S
Angle	40° to 67° SW Sector	60° SW Linear
Resolution	0.5° Step	1 Element Step
Frequency	5MHz	5MHz
Aperture	32E x 0.6	16E x 0.6
Focal Depth	None	None

Technique Development

PAUT scans from the shell surface(Left) and PAUT scans from the Head surface of welds CS-1 of welds CS-1

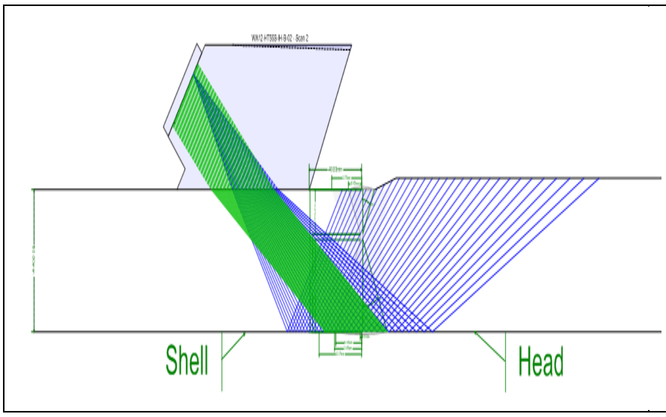

Figure 6: PAUT CS-1 at -40mm index skew 90°

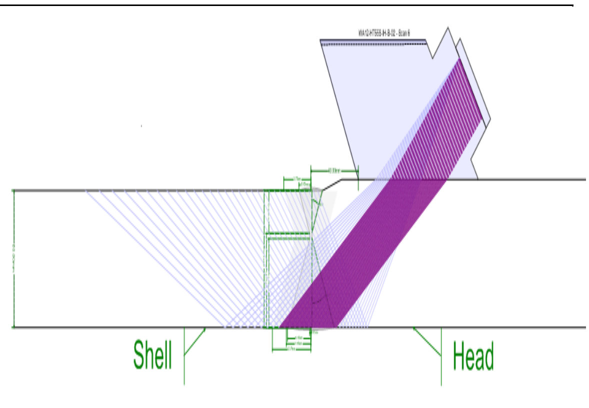

Figure 7: PAUT CS-1 at +40mm index skew 270°

Inspection Results – Flaw Example 1

Locations from the previously acquired data at ambient temperature were compared to data acquired during the on-line inspection.

In 2014, the focal law groups chosen were two sectorial beam sets with the scanning gain set to reference + 4dB and an index offset of 20mm (See Figure 8. Left) The location of the defect comparison is between 1833mm and 1946mm.

In 2015, the focal law groups chosen were one sectorial and one linear beam set with the scanning gain set to reference dB and an index offset of 40mm (See Figure 9 .)Right. The location of the defect comparison is between 1833mm and 1946mm.

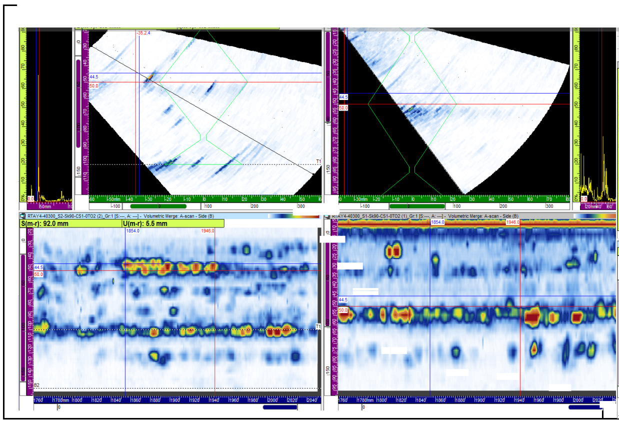

Figure 8 2014 1833 to 1946mm (Ambient)

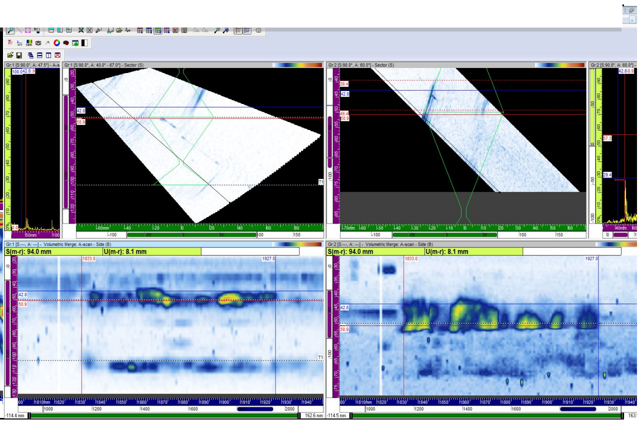

Figure 9 2015 1833 to 1946mm (HTPAUT)

Inspection Results – Flaw Example 2

In 2014, the focal law groups chosen were two sectorial beam sets with the scanning gain set to reference + 4dB and an index offset of 40mm (See Figure 10.) The location of the defect comparison is between 4000mm and 4200mm.

In 2015, the focal law groups chosen were one sectorial and one linear beam set with the scanning gain set to reference dB and an index offset of 40mm (See Figure 11.) The location of the defect comparison is between 4000mm and 4200mm.

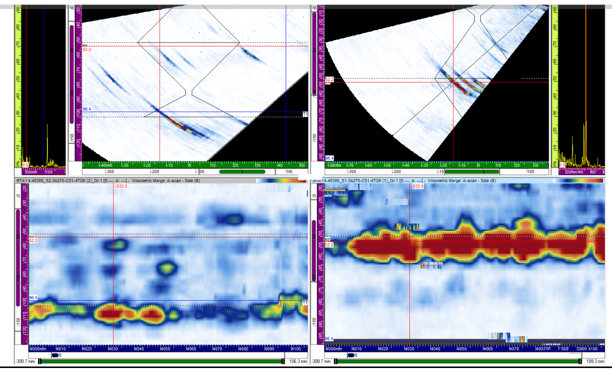

Figure 10 2014 1833 to 1946mm (Ambient)

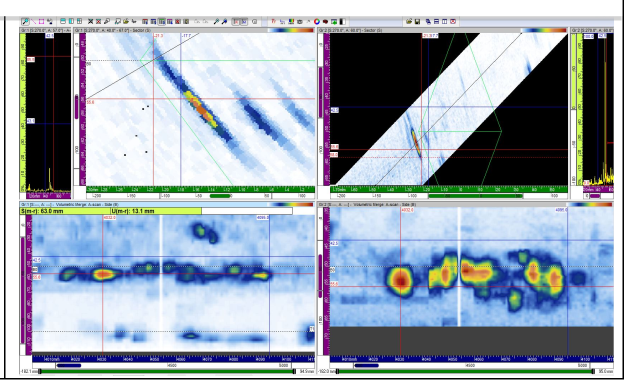

Figure 11 2015 1833 to 1946mm (HTPAUT)

CONCLUSION

The 2015 PAUT results showed good correlation with previous acquired data from 2014. System calibration was performed at the same vessel operational temperature to mitigate the affects of flaw index and depth offset of the beams at elevated temperature. A Focal law file is used by the phased array instrument hardware for beam formation. In some instruments, such as the OmniScan, law files can be exported, modified and re-imported to the instrument. This capability can be used for situations where linear approximation of the wave paths inside the wedge is invalid (inspection at elevated temperatures). This leads to non-optimal beam generation and inaccurate indication positioning. However law files can be modified to adapt the inspection condition." The path forward would be to import the focal laws created by ESBeamtool6 into the instrumentation.

REFERENCES

1. Mohammad, Hassan Marvasti and Sinclair, Anthony N. "*Development of Ultrasound Phased Array System for Weld Inspections at Elevated Temperatures,*" February 1991.

2. Mohammad, Hassan Marvasti, Mike Matheson, Michael Wright, Deepak Gurjar, Philippe Cyr, Steven Peters *"Phased Array Inspection at Elevated Temperature" June 2015*

3.