

## PHASED ARRAYS FOR DETECTING CRACKING IN BOLTS

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### Abstract

Phased arrays can be used for detecting cracking (and other defects) in high tensile bolts. The technique uses a “fingerprinting” approach to the bolts. In contrast to current code procedures where an operator manually scans a normal beam probe over a bolt and interprets the results, this phased array technique uses an S-scan and a mechanized scanner. Specifically, the phased array probe is mounted in contact on the head of the bolt, and performs a small angle longitudinal wave S-scan down the bolt. The array is mounted in a mechanized and encoded jig for 360° rotation round the bolt. Signals are received from the threads, bolt geometry and from mode conversions. In essence, the S-scan gives a fingerprint of the bolt at all depths and orientations when the operator scans round the bolt collecting data. Any perturbations from defects or cracks are typically very visible. Interpretation is much simpler than with alternative bolt inspection techniques. Some examples from calibration and cracked bolts will be shown. The technique can be fine-tuned for different bolt dimensions and features.

### Introduction

Current methods of inspecting bolts typically involve calibrating as normal, then scanning round the head of the bolt using normal beam probes (1). Interpretation of the results has proved difficult, as signals are reflected from geometry, bolt threads, and mode conversions occur, as well as reflections from cracks and corrosion. In addition, the usual ultrasonic issues arise: operator variability, no stored data, rough bolt surfaces, inconsistent coupling, no position data.

In view of the difficulty of bolt inspection, perhaps it is not surprising that there are not a lot of alternative techniques available. One of the few is the Centrifugally Guided Wave Technique (CGWT) from Southwest Research Institute (2). This technique essentially floods the bolt with ultrasound by using a large transducer on the end. Signals return from threads, geometry, mode conversions and defects as expected. However, it is possible to work out which defects are anticipated for a given bolt geometry from wave physics, and hence deduce if defects are present or not. Unfortunately, the analysis may not be trivial.

In contrast, phased arrays have proven to be readily applicable to bolt inspections. Phased arrays are a relatively new technology which permits electronic scanning, sweeping and

focusing of the ultrasound beam. Phased arrays are well described elsewhere (3), and will not be covered here. Bolt inspection can be performed with portable, encoded phased array units, as shown in Figure 1.

The initial phased array bolt investigations have been performed on cracked bolts from various sources (3). The principles remain the same, whatever the industry or application.



**Figure 1 Photo of Olympus NDT OmniScan performing an L-wave S-scan.**

### **Inspection Technique**

In the phased array inspection of bolts, the array is mounted in a jig on the top of the bolt (see Figures 2 & 3). The array is either in direct contact with the bolt, or uses a normal beam wedge. If in direct contact, a protective layer is required as bolt heads can be relatively rough.

Jig designs are established to accommodate a range of bolt forms, including varied bolt head sizes, stud end configurations, threaded shaft regions and nut/thread arrangements. The alignment of the jig on the bolt thread or bolt nut/head provides positioning of the array so repeatable results can be obtained and repetitive inspection of numerous bolts of similar design can be performed in a timely manner.



**Figure 2 Small bolt jig base unit (left) and (right) large bolt jig**

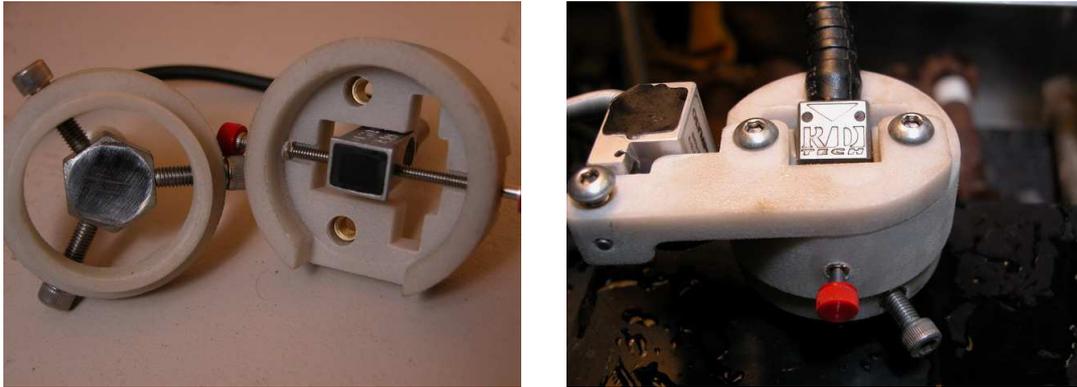
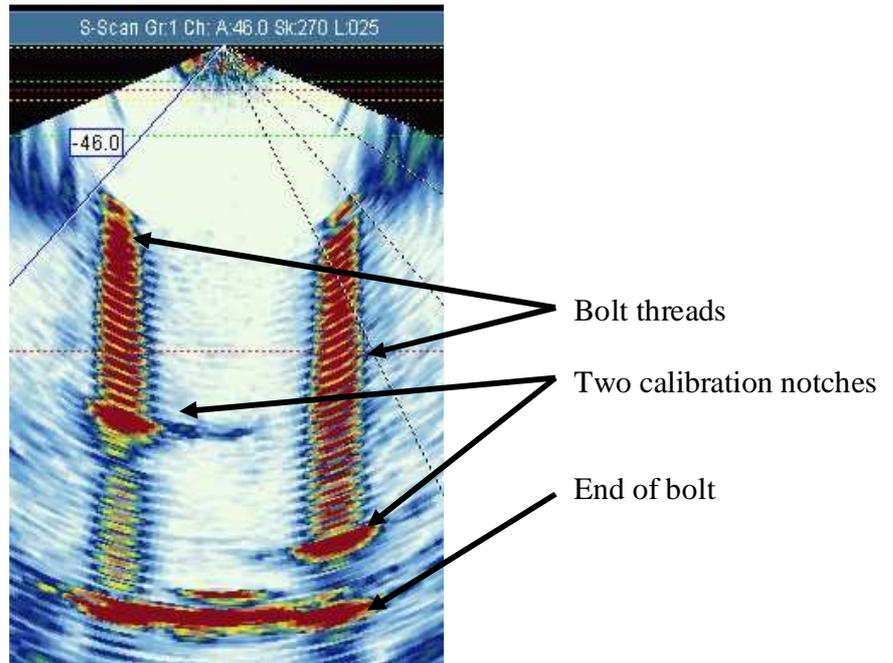
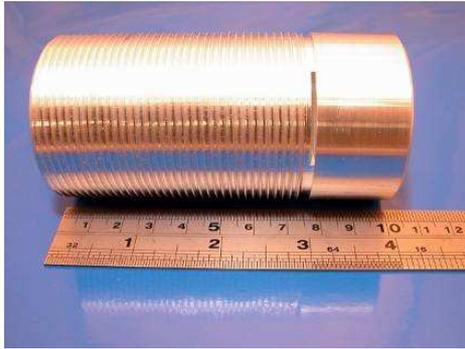


Figure 3 Left, ring and jig fixture. Right, fixture, probe and encoder on bolt.

As always, calibration bolts are used which are representative of the component to be inspected. The phased array instrument is set up to perform a small angle longitudinal wave S-scan (also called a sectorial scan, sector scan, azimuthal scan or swept angle scan). The beam sweeps through the vertical plane of the bolt, covering the threads, end, and body as shown in Figure 4 for a calibration bolt, which has a series of machined notches introduced at locations where crack initiation could occur.





**Figure 4 Top, scan of notched calibration bolt with threads, notches and end of bolt labeled. Bottom, photograph of notched calibration bolt.**

The array is scanned around the head of the bolt, and full data is collected and stored. In effect, the phased array instrument “fingerprints” the bolt for defects around the 360° circumference – for both cracking and corrosion in effect – and the data is stored and interpreted.

In contrast to both conventional bolt inspections and the CGWT, data interpretation is comparatively straightforward as the operator looks for anomalies in the data and predicted images.

## **Sample Results**

### ***Bridge Bolts***

Figure 5 (left) shows a schematic of a large bridge bolt with geometric reflectors and calibration notches marked. As the array is rotated around the head of the bolt, the geometric reflectors and mode conversions remain the same (assuming good manipulators), while notches and cracks will show as intermittent reflectors.

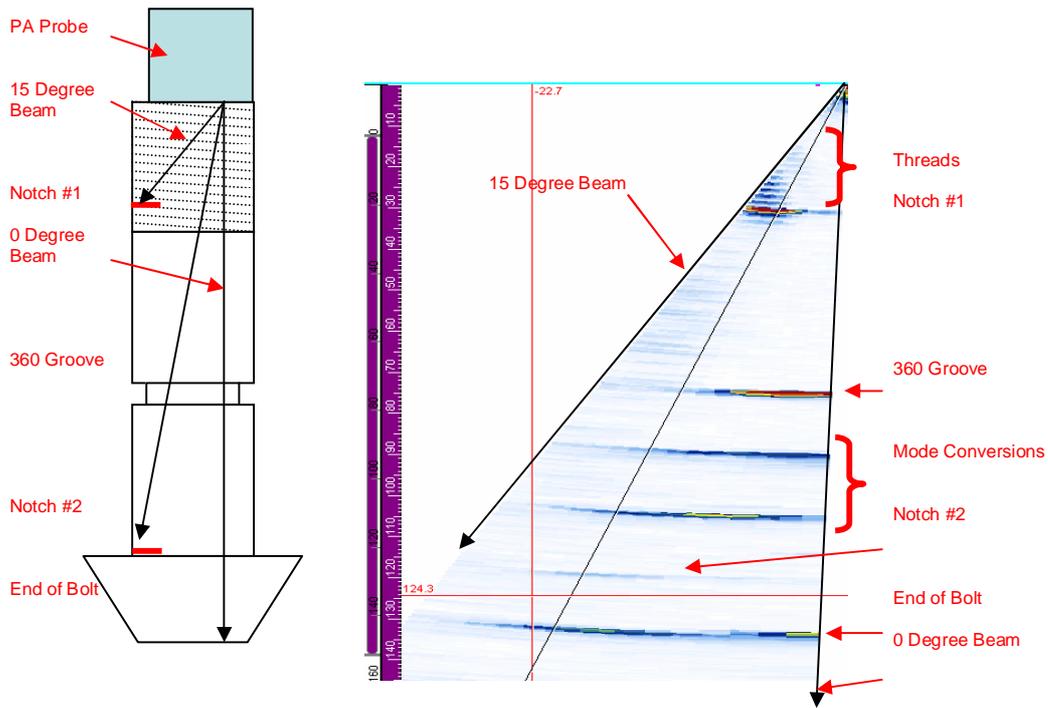


Figure 5 Left, schematic of bridge bolt with geometric reflectors. Right, S-scan of same bolt showing fingerprinting scan and calibration notches.

**Long shaft**

Figure 6 shows a long shaft – similar in principle to a bolt – with a known fatigue cracking location half way along the shaft.

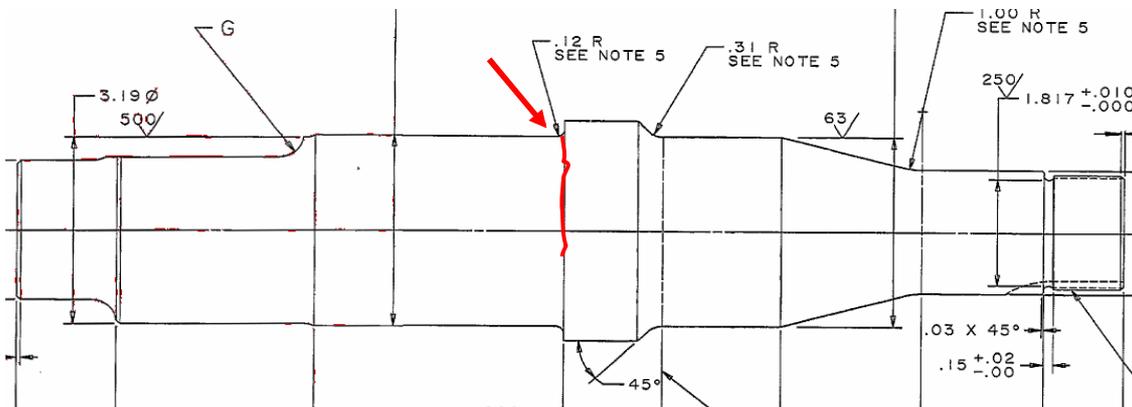


Figure 6 Drawing of shaft with known fatigue cracking (arrowed in red).

Figure 7 shows a typical scan of a similar shaft with reference notch.

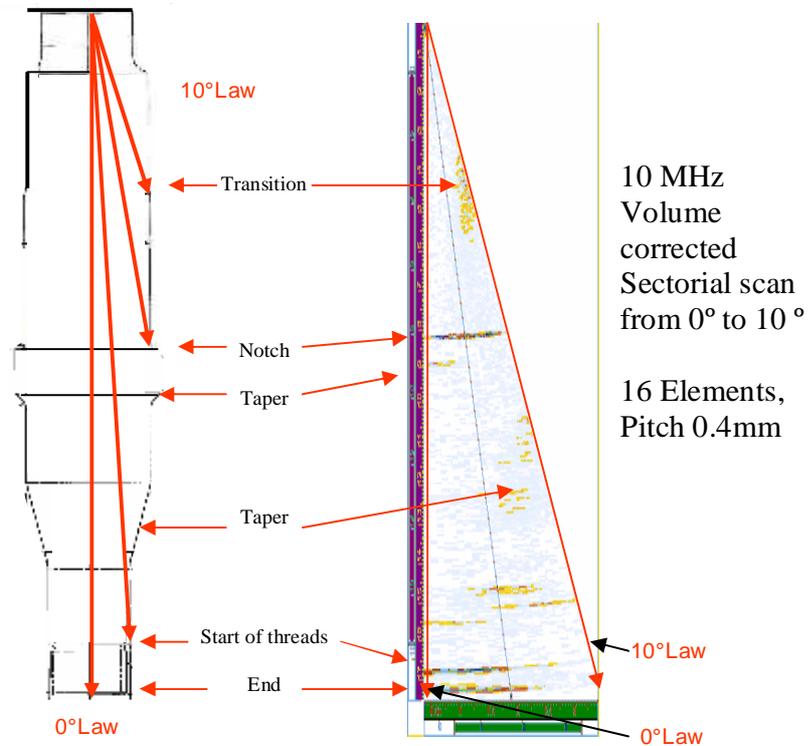


Figure 7 Left, schematic of shaft showing locations of notch, taper, threads etc. Right, S-scan of shaft.

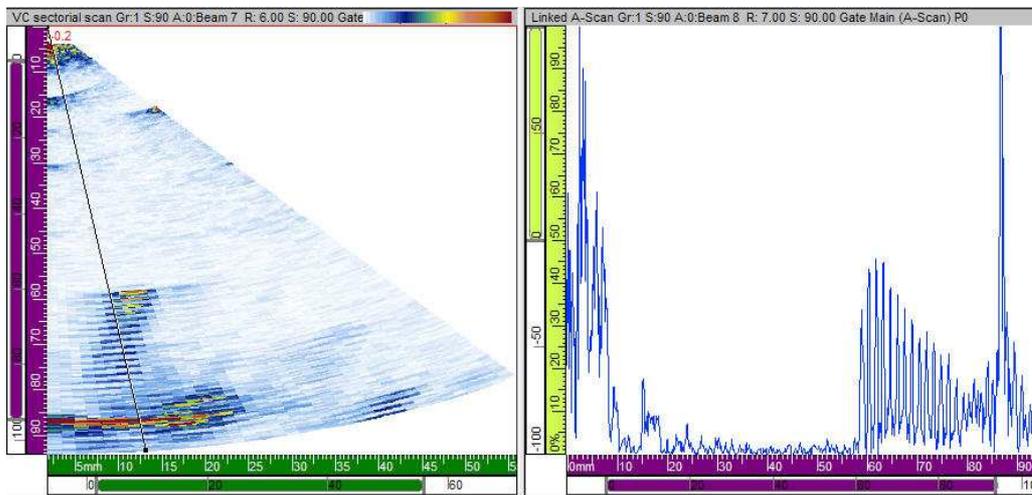
### ***High strength bolts***

Figures 8 to 13 are examples of high-strength structural bolts in high tensile steel (4) that have been in service. For this application the typical process requires obtaining some good samples to be used as the baseline reference. These bolts need to be clean and clear of any defects. One or two of these clean samples are selected for introduced targets with known characteristics. Electrical Discharge Machining (EDM) notches, saw cuts or a small thin grinding disc are used to introduce targets at specific locations either identified by historic failure or engineering requirements. These provide operators with an excellent reference for setting up the instrument and verifying the calibration.

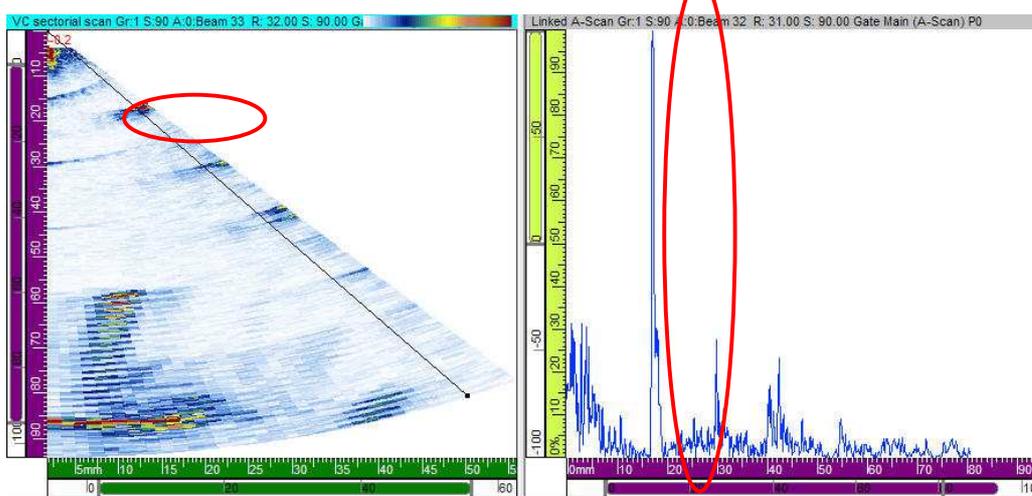


**Figure 8 Grinding disk cut targets introduced to provide known target reflectors**

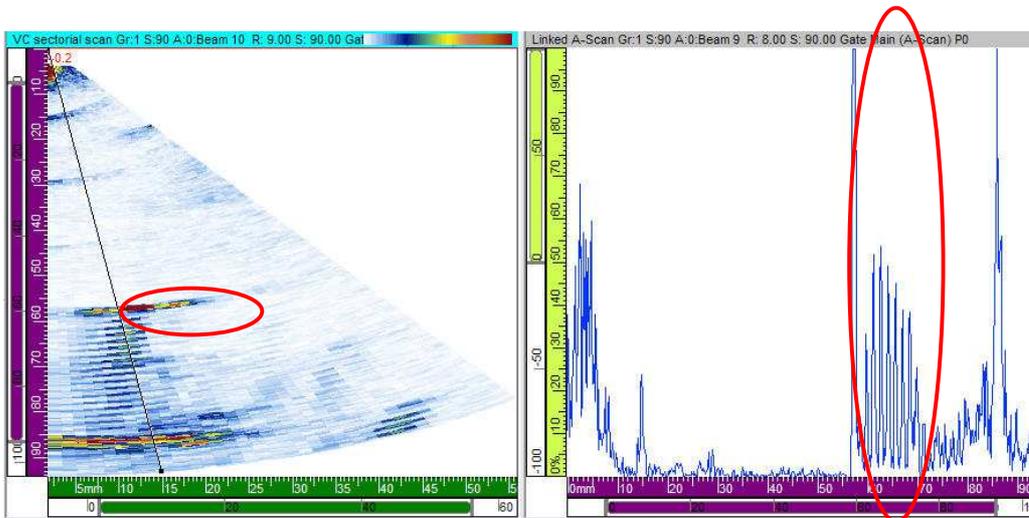
Targets positioned at thread transition and below the bolt head are most common locations, but historic failure locations must also be considered.



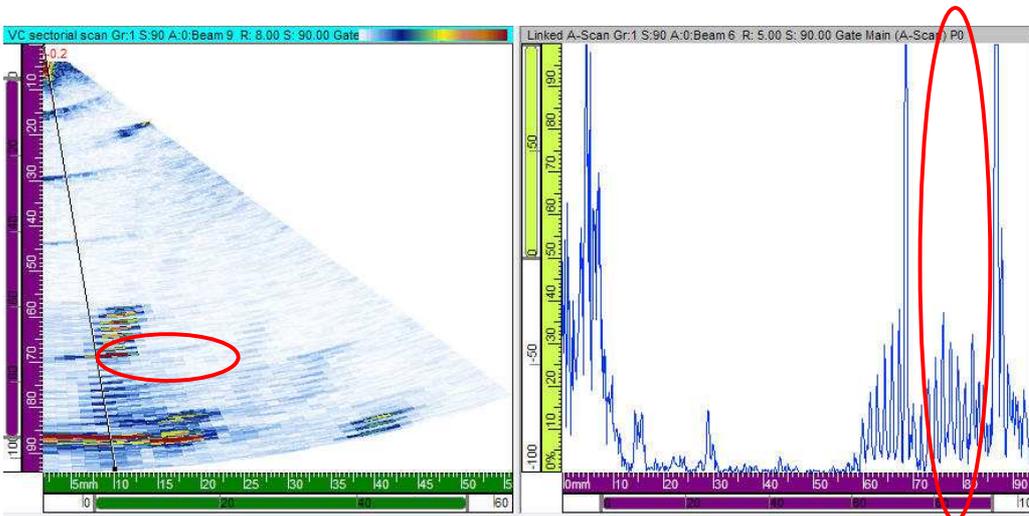
**Figure 9 Clean bolt, geometry and thread signals observed**



**Figure 10 Introduced target at base of bolt head (same location as the cracked samples)**



**Figure 11 Calibration bolt target located at top of thread section**



**Figure 12 Calibration bolt target located in thread section**



**Figure 13 Cracks noted at the base of the bolt head**

Crack response for this application in Figure 13 showed that no sound reached the thread section (see Figures 14-16). Multiples and what appear as numerous internal reflectors along with an increase in general signal to noise can be observed.

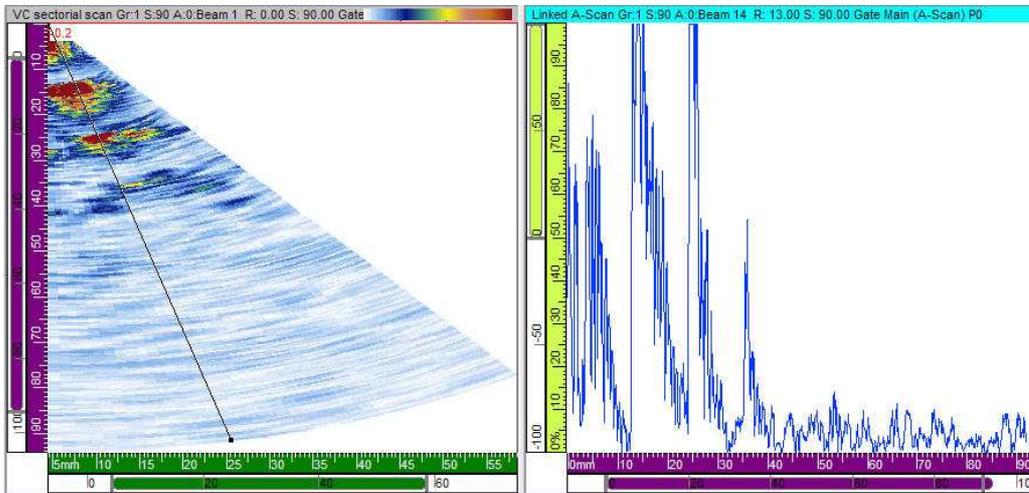


Figure 14 Crack sample Bolt-set 8 C sample (thread region totally obscured)

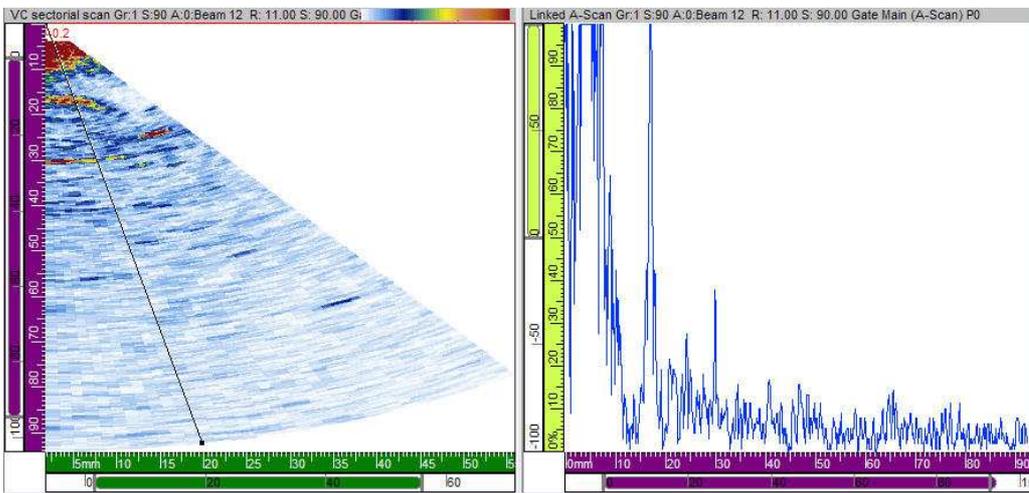


Figure 15 Crack sample Bolt-set 8 D sample (thread region totally obscured)

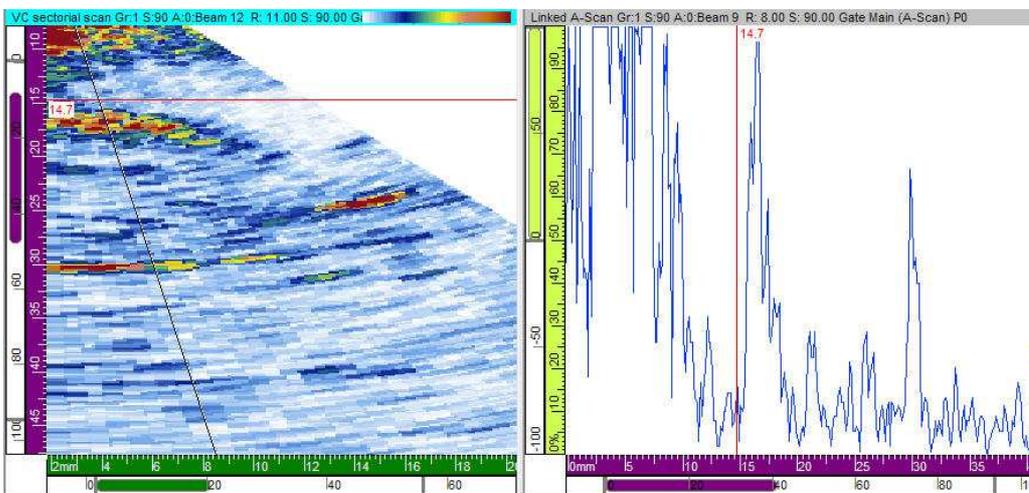
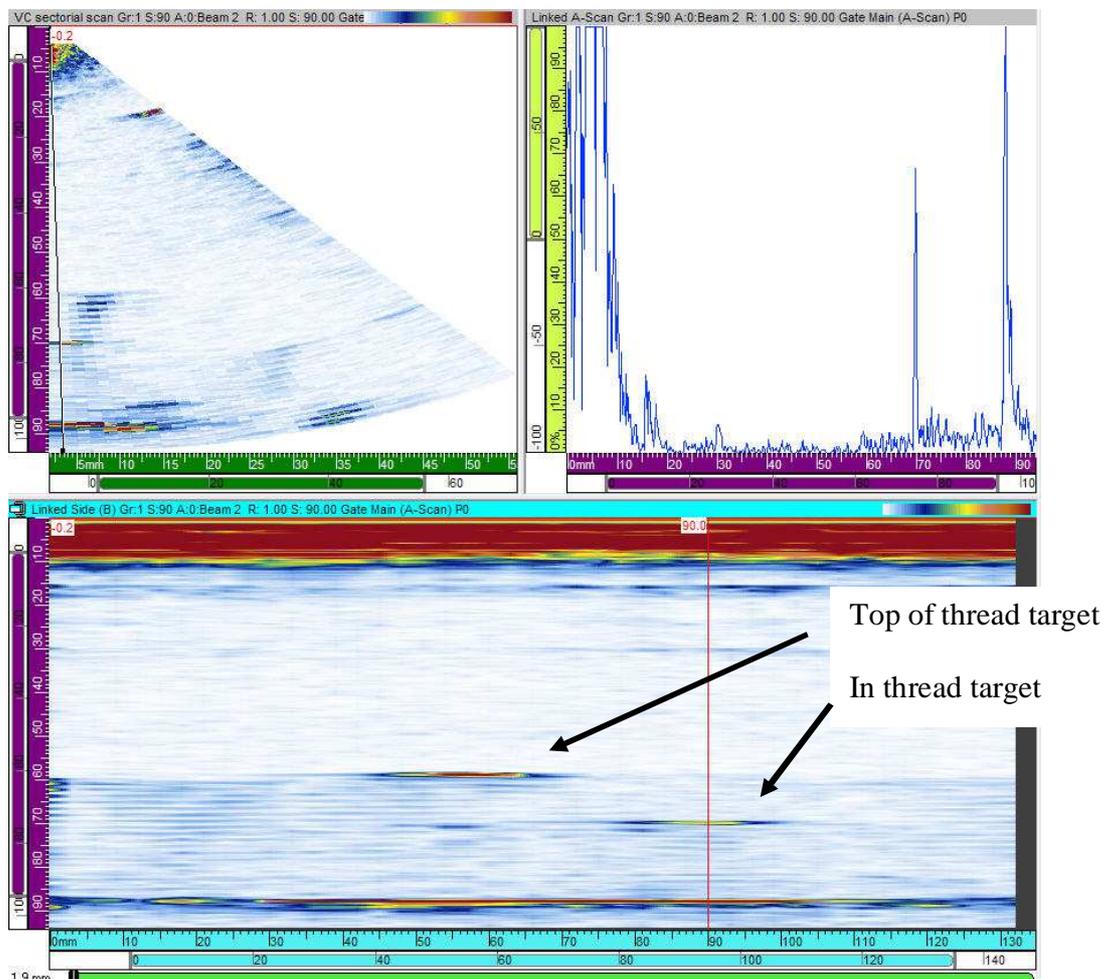


Figure 16 Crack sample zoom detail showing region below bolt head (Bolt-set 8 D sample)

### *Geometry vs. defects*

Operators can use the calibration sample to develop familiarity with the typical responses from the various targets introduced. The geometry signals must be understood and accounted for so that operators can quickly confirm quality data has been obtained. Ensuring the data quality is acceptable is critical for production scanning; in some cases the analysis of the collected data can be performed by other operators based in on-site trailers or office areas, or even remotely performed from another country. Development of analysis methodology and display options will enable rapid evaluation of the bolt data. Collecting the entire A-scan data set allows post analysis and will enable comparison of previous inspection campaigns.



**Figure 17** Calibration sample showing S, A and B-scan displays (top of thread and in thread targets visible in B-scan)

## Conclusions

- Detecting cracking in bolts using phased arrays is highly viable using commercial phased array technology
- This approach has significant advantages over current techniques: reproducible, fast, full data storage, auditable, interpretable locally or remotely.
- The technique needs a small mechanical jig and encoder for scanning
- There are many set-up options, depending on:
  - Physical contact area, length of bolt and thread section diameter dimensions
  - Material properties, grain structure and attenuation
  - Physical configurations and geometrical considerations
  - Phased arrays can be readily adapted to the different bolt conditions by using pre-prepared set-ups.

## References

1. ASME Boiler & Pressure Vessel Code, Section V Article 5, paragraph T-571, American Society of Mechanical Engineers, 2003.
2. G. Light, N.R. Joshi and S-N. Liu, "Ultrasonic Detection of Stress-Corrosion Cracks in Reactor Pressure Vessel and Primary Coolant System Anchor Studs (Bolts)", *Materials Evaluation*, Vol. 45, December 1987, p. 1413.
3. R/D Tech, "*Introduction to Phased Array Ultrasonic Technology Applications*", Quebec, Canada, Published by R/D Tech, 2004.
4. A490M Specification for High-Strength Steel Bolts, Classes 10.9 and 10.9.3, for Structural Steel Joints. Specification for Structural Joints Using ASTM A 325 and A 490 bolts, approved by the Research Council on Structural Connections; endorsed by the American Institute of Steel Construction and by the Industrial Fastener Institute