

Encoded Phased Array Bridge Pin Inspection

James S. Doyle
Baker Testing Services, Inc.
22 Reservoir Park Dr.
Rockland, MA 02370
(781) 871-4458; fax (781) 871-0123; e-mail jdoyle@bakertesting.com

Product Function and Form

Product Function - Certain bridge connection points are made using a pinned connection. The pinned connection allows for movement of the bridge within the connection. Typically two or more members come together and meet at this connection. The load is transferred from one member to the other through the pin. The location at which these two members meet along the surface of the pin create a shear plane upon the pin. These planes are the areas of interest, the most likely spot of failure. Being located between two members, visual access is impossible excluding many test method applications. Ultrasonic inspection from the pin end face is the best possible inspection method currently in use. Often times this is the only surface of the pin that is available for inspections. Figure 1 shows a typical bearing pin connection.

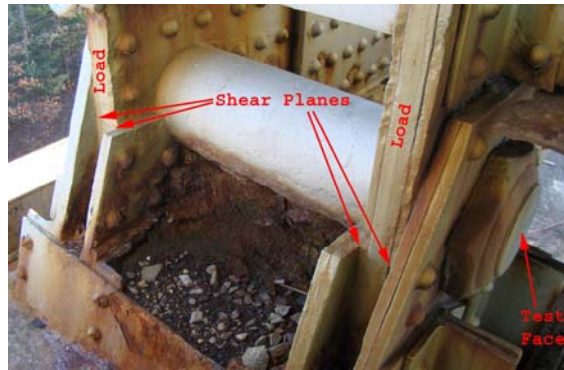


Figure 1: Typical bearing pin connection

Product Form - This paper will describe the pins as small, medium, and large in size. Figure 2 shows a small shouldered threaded 12" [305 mm] long pin x 4" [102 mm] diameter barrel with 3" [76 mm] diameter ends. The medium pin is a straight threaded 24" [610 mm] long x 6" [153 mm] diameter pin. The large pin is a straight 24" [610 mm] long x 10" [254 mm] diameter pin. The shape of shoulder is an important consideration as to whether or not the shear plane can be seen ultrasonically from the end of the pin. Ultrasonically, pins present a fairly straightforward inspection as they are essentially a bar stock product that may have predictable service induced circumferential flaws.

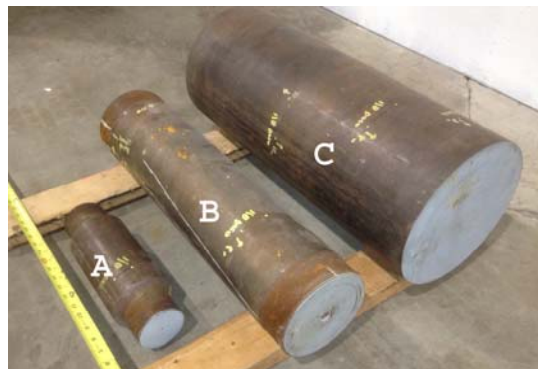


Figure 2: (A) small pin (B) medium pin (C) large pin

Conventional vs. Phased Array Inspection

A cursory comparison of a conventional ultrasonic inspection vs. a Phased Array ultrasonic inspection as it applies to this product is in order. Phased Array is still just UT - it's just a lot more of it! Phased Array allows for the electrical manipulation of the probe characteristics by inducing time shifts (phased) to the sent and received signals utilizing multi-element (array) probes for increased capabilities over conventional ultrasonics². The primary difference of these two techniques is with the creation of the ultrasonic beam. Once the beam is generated and induced into the piece it's all just UT. The primary advantage of a Phased Array inspection is that one can create multiple beam sets grouped and performed multiple times per second in order to interrogate different areas of the piece to be tested. A conventional inspection would be limited to a single beam. If multiple areas need to be tested, one would need to perform multiple scans using a Lucite wedge to induce a single beam at a given angle. These conventional scans would then need to be rastered across the pin with the raster motion continued in a full revolution of the pin face to provide coverage. Data points of any indications noted are jotted down and tabulated on a report form. This manual scan is not encoded and provides no permanent record of the test performed. Phased Array can provide a varied angle set to interrogate the periphery of the pin eliminating the need to raster the probe. This enables the scan to be encoded, providing proof of performance and a permanent record for future review and comparison of any indications found. Figure 3 shows the wave action of a two point wave source. Areas of maximum pressure are said to be constructive wave points, and areas of minimum pressure are said to be destructive wave points.

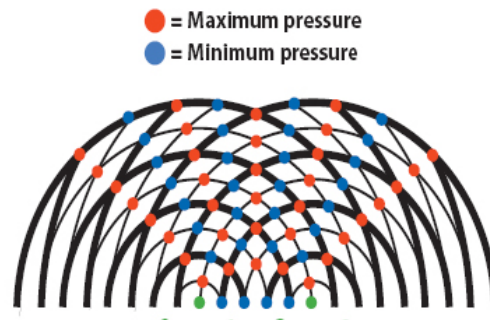


Figure 3: Two-point source interference pattern¹

Figure 4 shows a conventional 0-degree probe. Although a conventional probe is a single element, the element is comprised of many individual crystals. Each of these crystals on the face of the probe act as a single point wave source. The above interference pattern is therefore multiplied exponentially. Within the near field of the beam the constructive and destructive wave fronts are acting upon each other. At the end of the near field the wave fronts combine and progress as a singular beam subject to beam spread at this point.

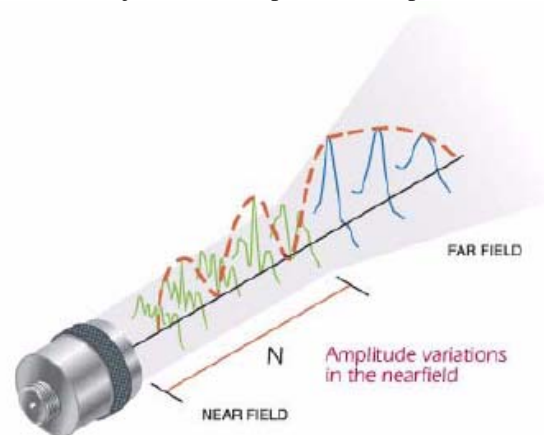


Figure 4: The sound field of a conventional 0-degree transducer¹

Figure 5 shows the process of creating an angular Phased Array beam. A Phased Array probe consists of a series of individual elements, each with its own connector, time delay circuit, and analog /digital converter². Each of the elements are fired at a certain time or phased. The phasing takes advantage of the constructive forces within the beam to provide the required beam angle.

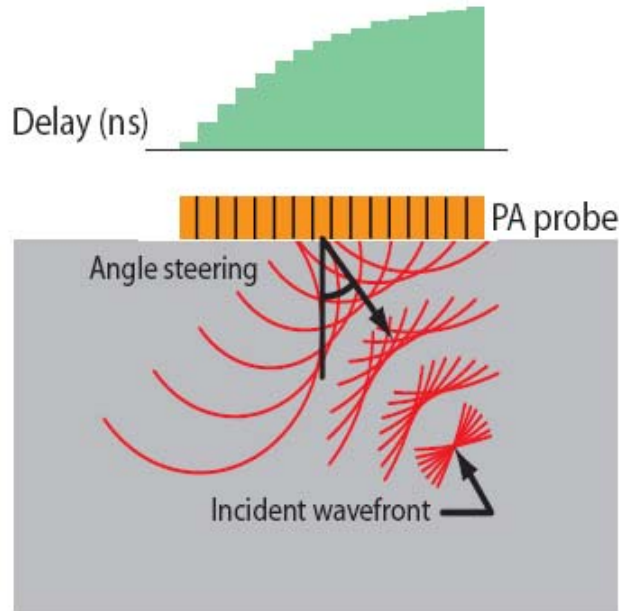


Figure 5: An angle beam generated by a flat probe using a variable delay¹

Developing an Effective Phased Array UT Scan Plan

The process starts with obtaining information on the pin to be tested. Fairly accurate dimensions of the pin are needed in order to develop an effective scan plan. Shop drawings, as built data, or actual field measurements are required. In some cases a pin will be fabricated as a calibration standard. Additionally it is important to know where the shear planes are located within the connection. These are the areas of likely failure and are the areas to direct coverage towards. Most pins afford access to both ends therefore the test is performed from both ends. With these dimensions the pin is drawn into a computer modeling drawing program. At this point it becomes apparent how a well thought out method of testing this pin will be required. The drawing program comes loaded with a variety of probes that one can choose and place on the end of the pin. One can move the probe up and down the face of the pin and vary the beam angle set and see in real time just where the sound beam will interact with the pin. Figure 6 shows a typical shouldered threaded pin. Typically, three groups are set up and one can think of each group as a channel. In essence the three groups are near, middle, and far. The near group, depicted as the red beam set, will just look at the near side threaded section. This beam set could be a refracted L wave, or if the angle is too acute, a refracted shear wave can be used. The middle group, depicted as the blue beam set, will look at the barrel of the pin. This beam set is usually a shallow angle refracted L wave beam set that will cover the shear plane areas of the pin. If the pin is fairly short you will be able to look at both of the shear planes. If the pin is fairly long it may be best to only look at the near shear plane. The third group depicted as the gray beam set is the far channel that looks down the entire length of the pin. This is usually just a single 0-degree beam, and is the equivalent beam set of a conventional UT examination. This beam set serves three purposes. First and most importantly, it will image major flaws within the barrel of the pin. Second, it will provide distance measurements of the overall length of the pin, and any shoulder that may be present. Third, it provides what should be a consistent backwall echo that confirms proper couplant has been maintained. The other groups do not provide a back wall response needed to prove one has maintained couplant, so this is actually the group to monitor while the scan is being performed.

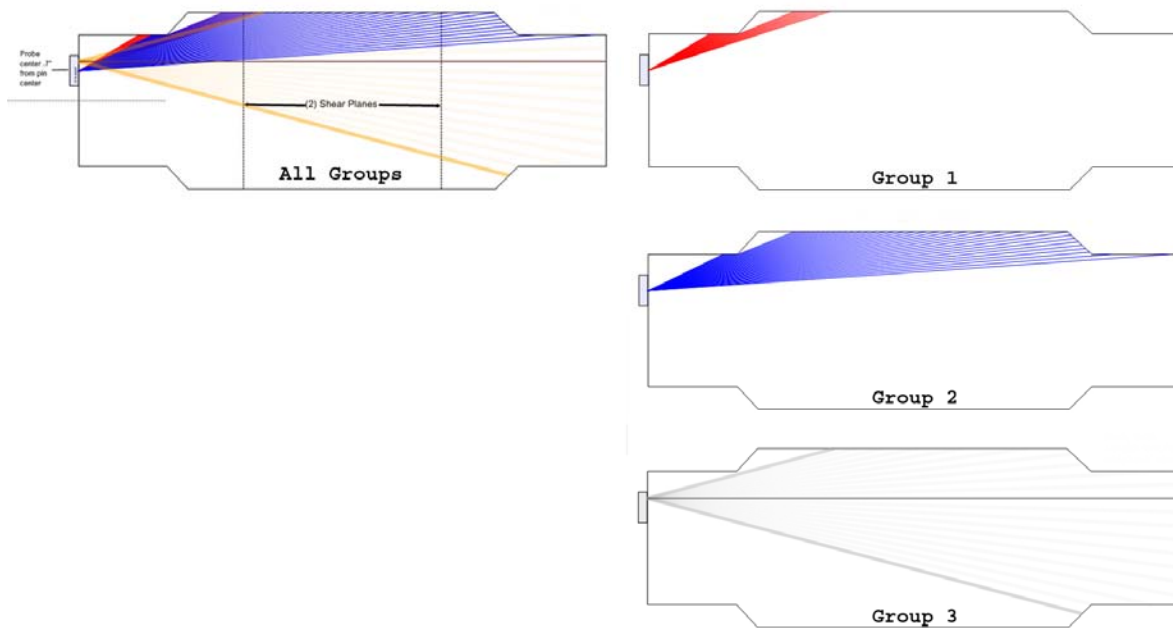


Figure 6: Typical scan plan for a shouldered threaded pin

The key philosophy of this test method is to determine the ideal position to locate the probe off of the pin center and develop group one to see the threads and group two to see the shear planes. One is in complete control of this probe. The specific beam angles can be generated for each of these groups. The group three inspection can also be improved by introducing beam spread of the 0-degree beam. Phased Array has the ability of inducing beam spread on this beam set. Typical inspections try to limit beam spread; it is usually an undesirable consequence. By firing only a few elements of the probe one creates a smaller effective probe size that will increase beam spread. Please note in Figure 6 that the beam spread has been shown in group three. Upon completion of the scan plan complete coverage along the periphery of the pin is provided for with a single rotation of the probe about the pin centerline performed from both ends of the pin.

Performance of the Phased Array UT Scan Plan - Data Gathering

Once the scan plan has been developed, the test parameters are input to the Phased Array unit. Modern units simplify the parameter inputs using group wizards. The probe element is then calibrated, typically using a single side drilled hole, again using a wizard function. Once the probe has its delay and sensitivity calibrations performed, the response from the reference hole will be equal, set to 80% full screen height at each angle in the given beam set. The final calibration required is to construct a Distance Amplitude Correction curve (DAC) using a series of equal diameter side drilled holes at increasing depth from the test face surface. Alternately, a series of equal depth saw cuts at increasing distances from the test face surface may be used. This calibration essentially increases the gain as the distance to each of the reference reflectors is increased. This calibration accounts for the loss of signal amplitude due to attenuation. Once performed, the response from each of the reference reflectors will be equal, set to 80% full screen height. Each end of the pin has to be prepared for inspection. Cover plates need to be removed. Rust, scale, and paint are to be removed. Large pins with center through bolted cover plates require building in a center bolt. Medium and small pins usually have some type of machine center point. Paint globs and debris need to be cleaned out so that the fixture center bolt can seat properly. The fixture may need adjustment of the centering bolt since the machined center point of the pins may vary. The probe is set into a fixture as shown in Figure 7 that includes an encoder and is irrigated using water as the couplant supplied by a battery operated pump.

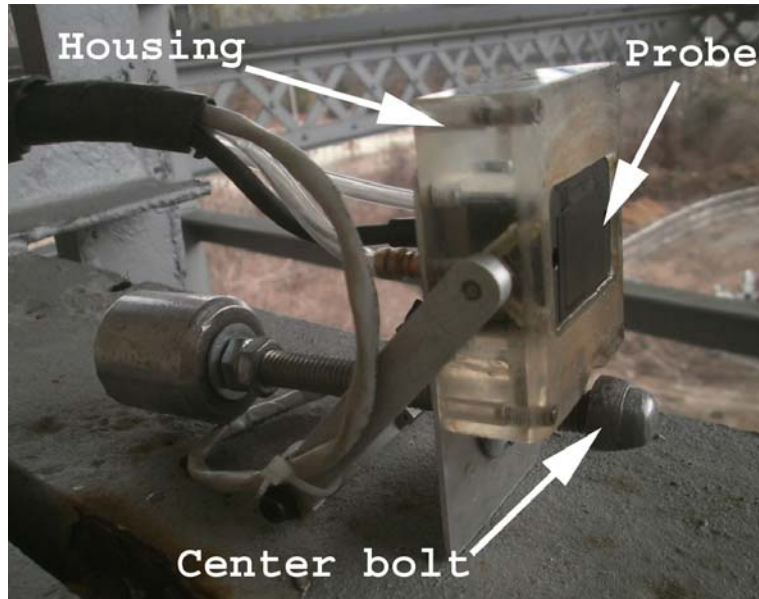


Figure 7: Close up of irrigated medium probe fixture

There are different size pins so different size probes and fixtures are used as shown in Figure 8. The given size would be based on the diameter and configuration of the exposed ends of the pin. An encoder is attached to the fixture. An encoder is a simple device that keeps track of where the probe is located. Once attached to the fixture the encoder requires calibration. This is done by showing it one revolution and telling it how far it just traveled. This process is usually set up telling it 12" so that the output reads as clock positions. The clock positions are segmented so you can approximate 2:30 or 2:45. Couplant is applied to the pin and onto the face of the probe and the probe is set at 12:00 top dead center. Next water is applied. Water has the consistency of water. This combination of using both a commercial grade couplant and water has been found to work best. The encoder polarity is verified, normal would be clockwise and inverse would be counterclockwise. The inboard end of the pin is scanned going clockwise. The outboard end of the pin is scanned counterclockwise. Using this method any flaws found are reported with clock positions as viewed from the inboard end of the pin. Flaws seen from both ends at 9:00 will show up at 9:00 on both scans. With the unit set on channel three, one hits the play button. This sets the encoder to zero and prepares the unit for the scan. The probe is rotated one full revolution monitoring the unit for two things. First couplant is being maintained, as seen on the A-scan or the C-scan as signal amplitude. Second is data drop out, which happens if the probe is moved too quickly, it does not have the time required to do all of the programmed tasks (beam sets). Longer pins will require a longer range setting further slowing the available scan rate. Data drop out shows on the screen as a black line and as the name implies no data for that point is obtained. Once the scan is complete, the data is reviewed for completeness and saved.



Figure 8: (A) small pin scanner (B) medium pin scanner (C) large pin scanner

Data Analysis and Reporting

The data is saved to a card and is downloaded to a PC for review. The first group is reviewed looking for any problems in the threaded area. The second channel is reviewed looking for any problems in the barrel of the pins. The third channel is reviewed and the length and the depth to any shoulders are recorded. Indications exceeding 20% full screen height are reported recording the amplitude, depth, clock position, and angle. Two views of the pin are presented to the owner - both a C-scan and a B-scan. These two views can give you a quick idea of where any problems have been located. Indications are color-coded based on signal amplitude (as blue low to red high) and shown by clock position. In reviewing the scan one must still observe the A-scan signal in order to correctly classify the indications found. Mechanical grooves have a singular mechanical look to them. They present a signal that looks identical to the saw cuts that are placed in reference pins. Cracks on the other hand look like cracks. Very few cracks are singular. They have facets and faces. They travel along grain boundaries. They have peaks that develop and shift in amplitude as one scrolls the data cursor through the angles and as one scrolls left and right within the scan. A sectorial scan or S-scan is also available for review. This scan is a side view of the beam set that has been sent into the pin. Often times a crack tip diffraction signal can be seen in this view to assist in the characterization of the flaw. The following figures are screenshots taken of a typical calibration standard containing saw cuts as reference reflectors. While viewing the data file C-scan one can scroll left to right, which would replicate rotating the probe clockwise from 12:00. Scrolling the data cursor up and down would replicate scrolling up and down through the given beam set angles. The following figures are similar with the data cursor highlighted and that point is displayed as the A-scan and S-scan. Please note that this calibration pin has a cotter pin hole located at 12:00 and 6:00.

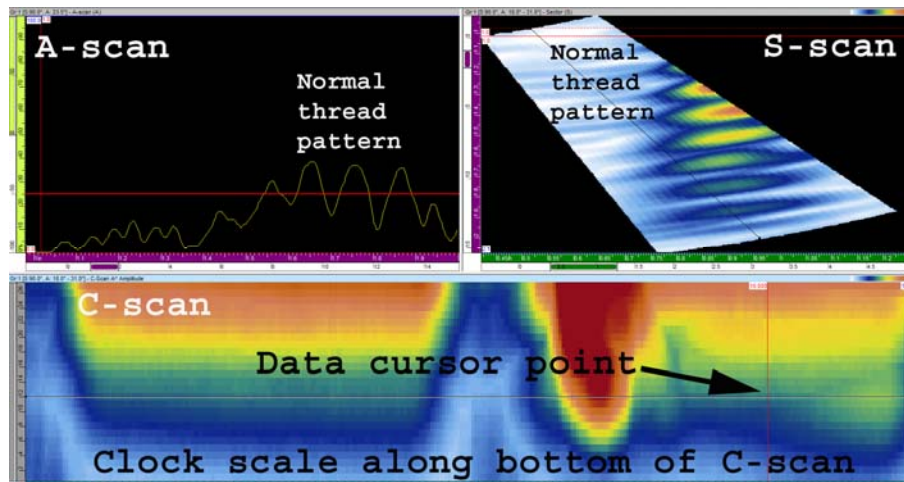


Figure 9: Group 1 normal thread data point

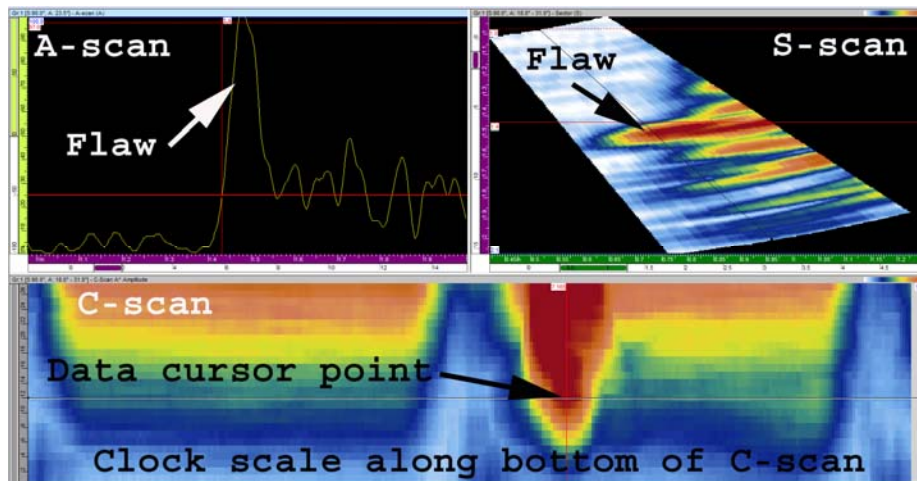


Figure 10: Group 1 thread saw cut calibration reflector (1.4" [36 mm] deep) data point

Figures 9 and 10 show the same C-scan of Group 1 – the data cursor has been toggled to show the A-scan and S-scan images of the reference reflector saw cuts. The loss of signal due to the through drilled cotter pin hole is seen at 12:00 (both the left and right edges of the C-scan display) and at 6:00 (the middle of the scan). The saw cut is apparent on the S-scan and appears to bleed inward from the root of a thread. Also note that in the Figure 9 S-scan the threads are stacked vertically.

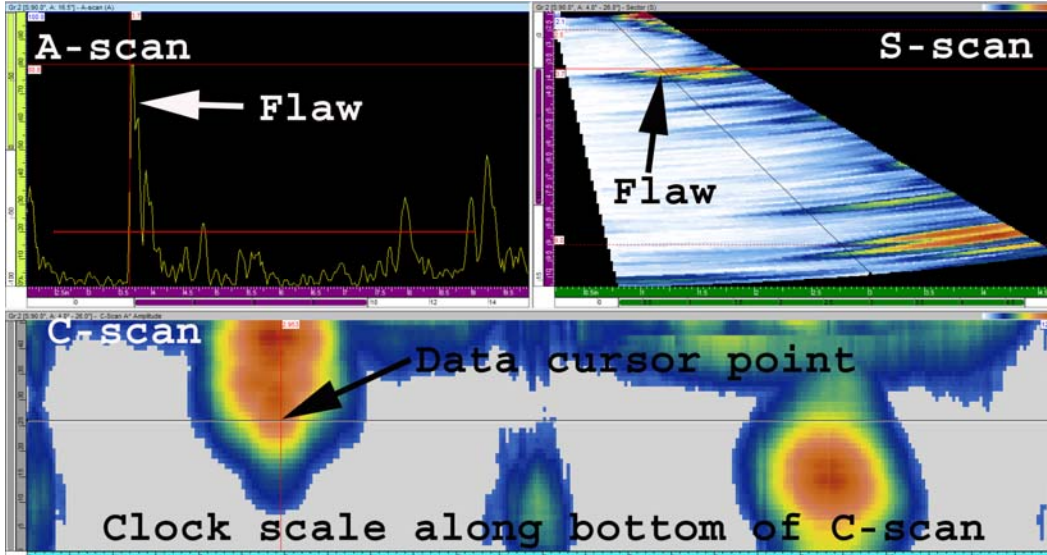


Figure 11: Group 2 barrel saw cut calibration reflector (3.7" [94 mm] deep) data point

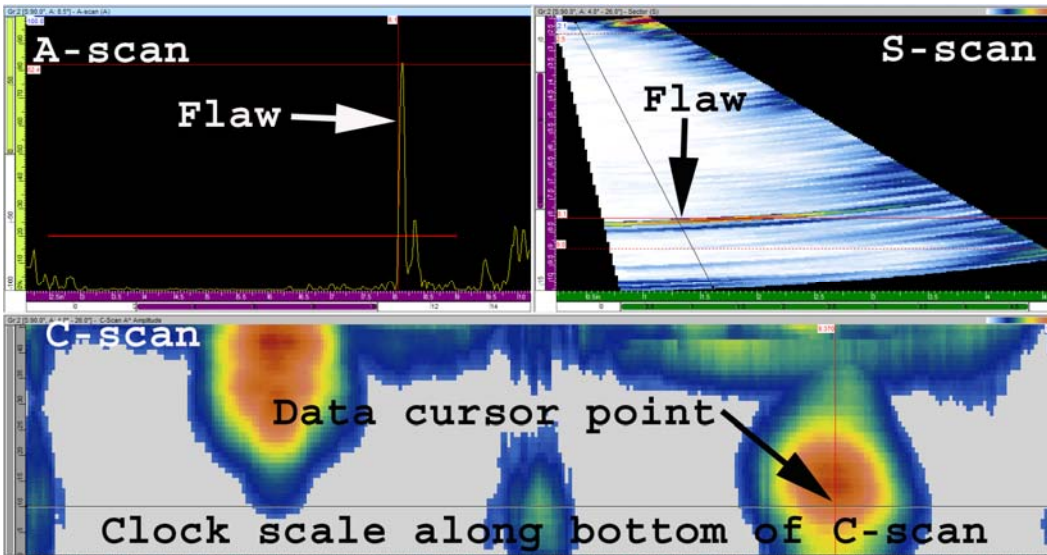


Figure 12: Group 2 Barrel saw cut calibration reflector (8.0" [203 mm] deep) data point

Figures 11 and 12 show the same C-scan of Group 2 – the data cursor has been toggled to show the A-scan and S-scan images of the reference reflector saw cuts. The through drilled cotter pin hole is seen at 12:00 (both the left and right edges of the C-scan display) and at 6:00 (the middle of the scan). Note that in both of the S-scan displays the two saw cuts are stacked vertically.

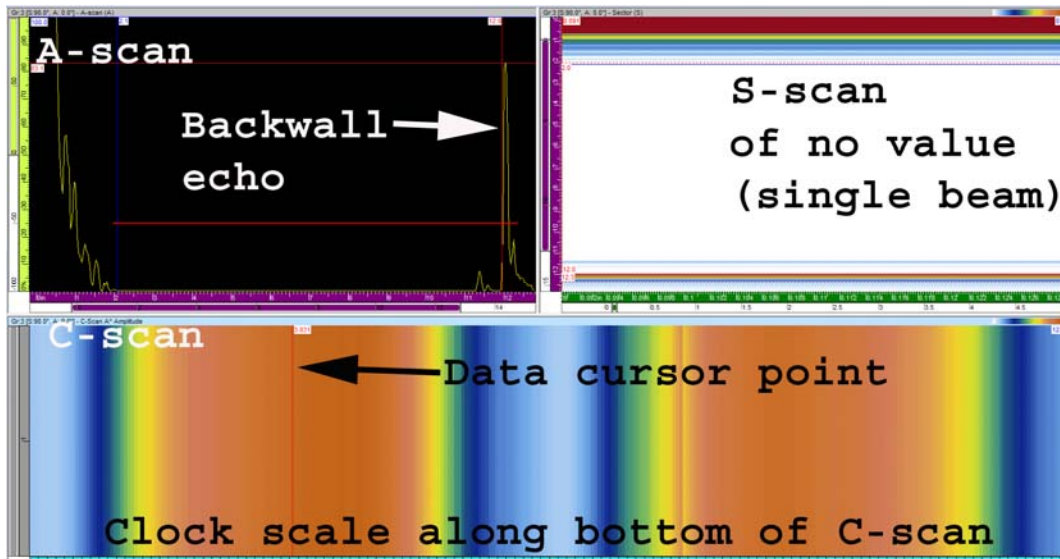


Figure 13: Group 3 back wall (at 12.0" [305 mm]) data point

Figure 13 shows Group 3 - the data cursor has been set to an arbitrary point at 3:00. Again the loss of signal due to the through drilled hole is seen at 12:00 (both the left and right edges of the C-scan display) and at 6:00 (the middle of the scan). The A-scan shows the end of the threaded section at the left edge of the display. There is a small indication at 11.5" [292 mm] deep due to the cotter pin hole at the far end. The pin length is shown at 12" [305 mm].

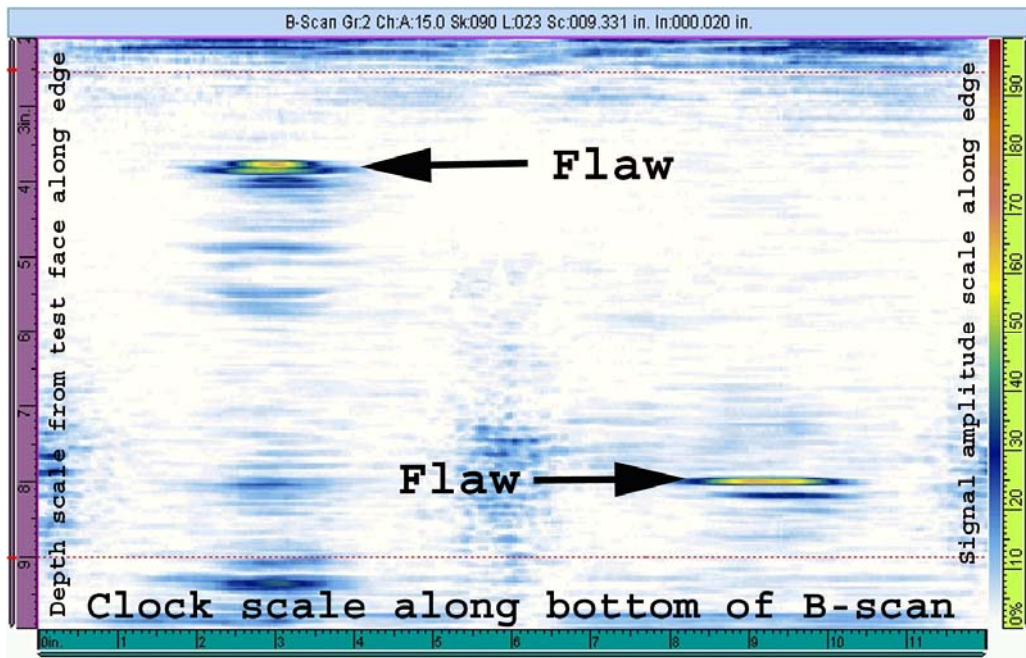


Figure 14: Group 2 B-scan image showing the two reference saw cuts

Figure 14 shows a B-scan view of Group 2. The two reference saw cuts can be seen at locations 3:00 and 9:00. This print out could be rolled out into a cylinder, which would closely replicate the periphery of the pin barrel.

REFERENCES

- 1 *Phased Array Testing: Basic Theory for Industrial Applications*, Olympus NDT 2010.
- 2 *Phased Array Training Course*, Davis NDE 2011.

This document was produced and submitted to ANST for presentation. ASNT retains copyright.