

## KAERI Feeder Tube Inspection Using EMAT Generated Circumferential Guided Waves

**Objective:** Inspection of small diameter pipe with complex curves. The principal defects of interest are axial cracking at bends.

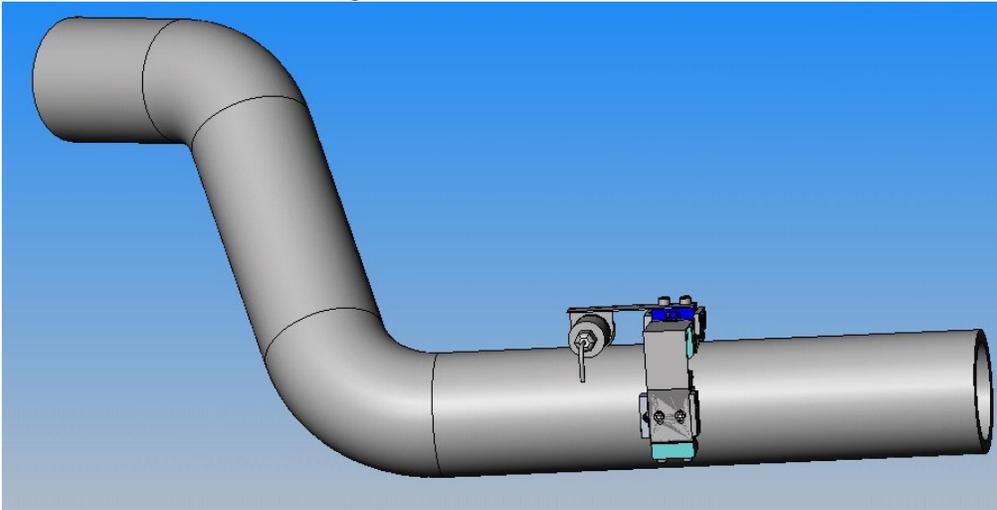
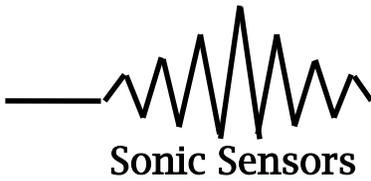


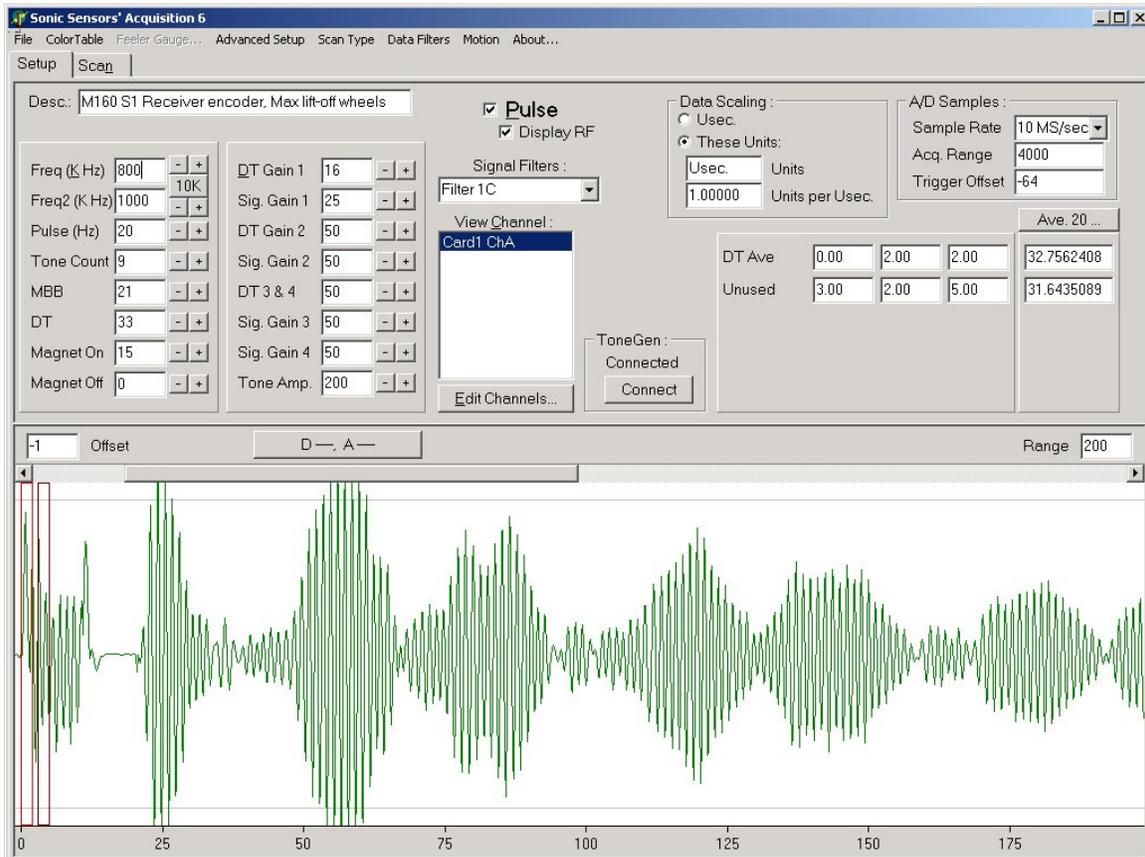
Figure 1: Illustration of Circumferential Transducer on pipe with complex curves.



Figure 2: Sample pipes used in prototype development. One sample has an axial EDM notch in the middle of a bend the other sample is free of cracking.



**Acoustic Design:** To optimize detection of axial cracking, a Lamb wave mode with efficient EMAT transduction, and maximized tangential displacements were chosen. The S2 mode at a thickness to wavelength ratio of 0.9 was found to be optimal for the detection of axial cracking. Due to the curvature effect of the pipe on the boundary condition of the guided wave the dispersion curves were slightly different from the plate wave dispersion curves. The optimal configuration for the Integrated EMAT System has been shown in Fig. 3. Some adjustment of DT and signal gain will be required in each specimen to optimize the data acquisition process and prevent saturation of the signal.



**Figure 3: Configuration for S2 wave mode on samples with a wall thickness of 0.290 inches (7.4 mm)**

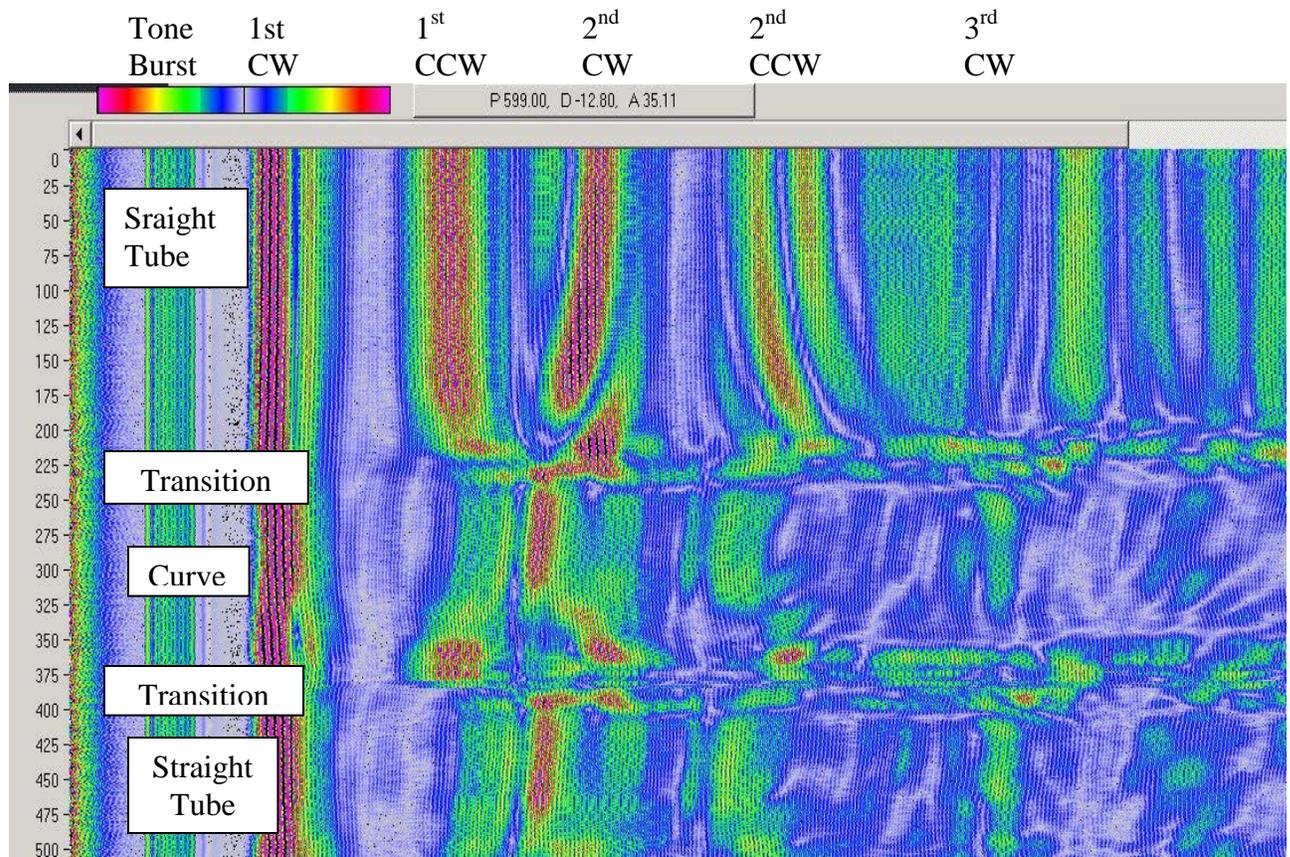


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**Results:** Interpretation of the signals are best performed in the Stacked A-Scan display, or E-Scan. Three features are used to detect cracking. Axial cracking can create an echo, a shadow, and or interference patterns. The presence of a crack can cause significant scattering and interference patterns which are clearly evident on the E-Scan.

These features are obvious in a straight section of pipe, but unfortunately the transition from a straight section of pipe to a curve creates a signal drop out due to the wave being redirected in a helical path away from the receiver. This effect is unavoidable due to the manufacturing method of the bending process. The curvature of the pipe starts in the intrados before it starts on the extrados. For example if the guided wave is generated on the extrados and is therefore aimed circumferentially around the pipe, the curvature on the intrados deflects the wave in a new direction axially down the pipe length and misses the receiver. Once the transducers enter a portion of the bend with a continuous curvature the guided wave travels around the pipe in one axial location in a single diametral plane and thus appears on the E-Scan.

The Stacked A-Scan or E-Scan of Figure 4 displays the scan from straight pipe through a bend and into another straight. The vertical lines represent the various signals arriving at different times. These are labeled across the top of Figure 4.



**Figure 4: Scan of a feeder tube with out cracking. The Clockwise signals were labeled CW and the Counter Clockwise signals labeled CCW. Notice multiple revolutions around the pipe.**

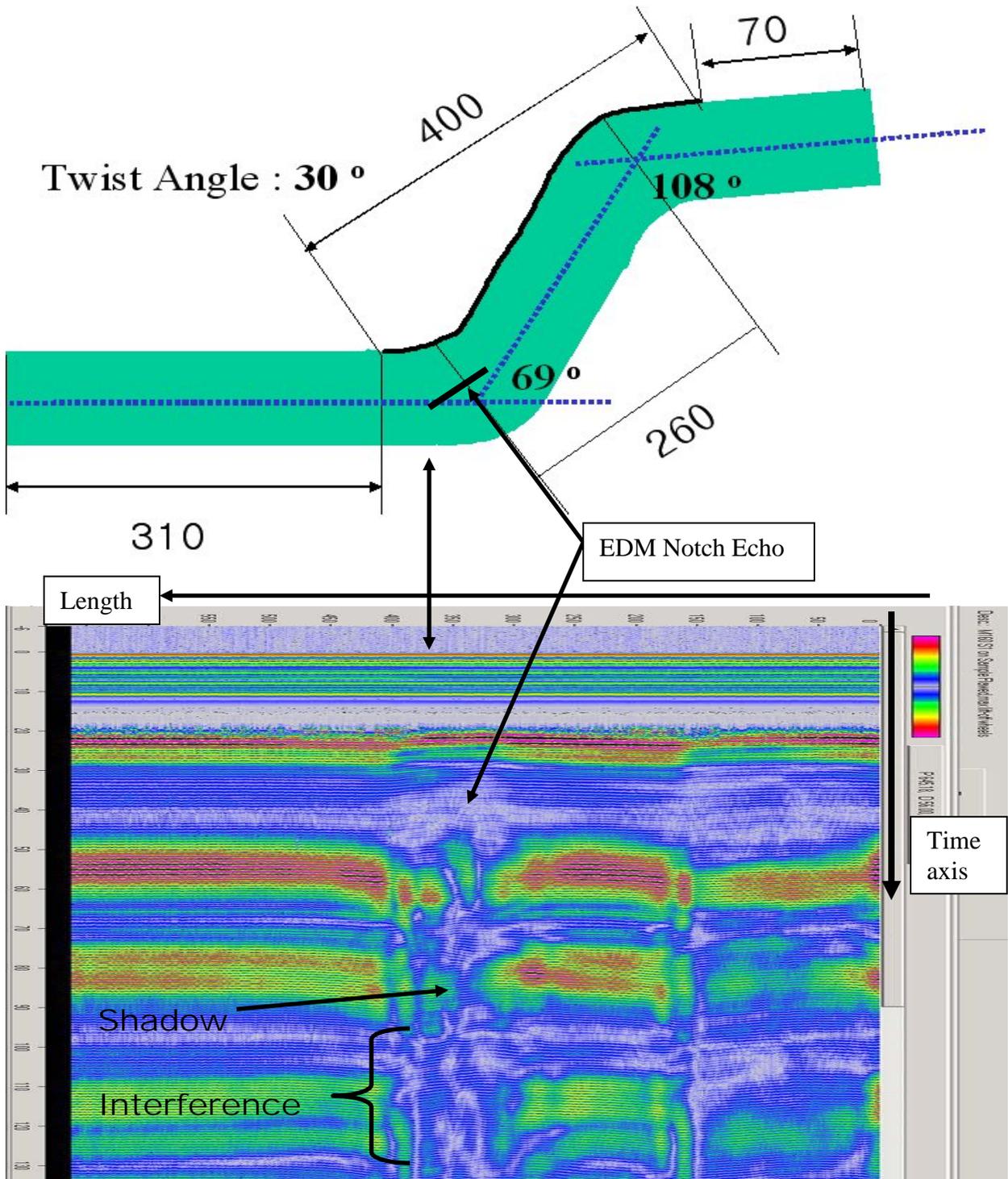
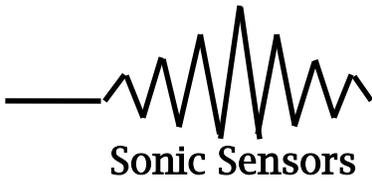


Figure 5: The Stacked A-Scan or E-Scan rotated 90° to align to the pipe illustration. The horizontal axis is the distance along the pipe, the vertical axis is arrival time of the acoustic signals. The color scale is the amplitude of the received acoustic signal shown in the upper right hand corner.



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170 Granada Drive, Suite D; PO Box 1889  
San Luis Obispo, California 93401  
PH: 805-545-0675 FAX: 805-545-0374

of **EMAT Ultrasonics Inc.**

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### E-Scan Interpretation

Axial cracking shows up as a deviation from the typical pattern shown in Figure 4 including the discontinuities caused by entering and leaving each bend. Proper interpretation depends on correctly identifying these two transitions at each bend. Once the transitions are located discontinuities in the curves become the main objective. Three features can help identify a crack. These features are identified individually below

### ECHOES:

The most definitive indication of an axial crack is the presence of an echo. An echo is not easily confused with the straight to curve transition especially if it does not occur during one of the “DT” circumferential signals. Figure 8 and 9 show echoes occurring at different times. The arrival time of the echo depends on the position of the crack relative to the position of the transmitter and receiver. The complex curves of the specimen dictate the position of the transducer, and the scanning direction dictates the encoder position. There were two transducer carts delivered. Each cart had a different orientation of transmitter and receiver. Figure 8 illustrates two positions for transmitter and receiver. Figure 9 and 10 show the different arrival time of a notch echo resulting from switching the transmitter and receiver positions.

### SHADOWING

The presence of a crack can cause a shadow in the normally occurring “typical” circumferential signals. The shadow is evident by a lack of signal amplitude which causes an abrupt change in the vertical lines of the E-Scan. The straight to curve transition drop-outs make this a difficult feature to rely on. The transition zone essentially appears the same as a shadow. Viewing the multiple rotation signals can help clarify this situation. Figure 5 and 12 show examples of a shadow.

### INTERFERENCE

Interference patterns are a secondary effect of scattering. An echo or shadow result from the redirection of a sound wave. These redirected waves interact with each other to form odd patterns in the otherwise “smooth” E-Scan. The straight to curve transitions typically occur as simple drop outs and do not cause “strange” interference patterns. However interference patterns are not very definitive and rather subjective, such that these features can be a supporting argument for the evidence of a crack, but not a reliable indicating feature to base a judgment on. Perhaps interference should only be used as a supporting argument for an indication.

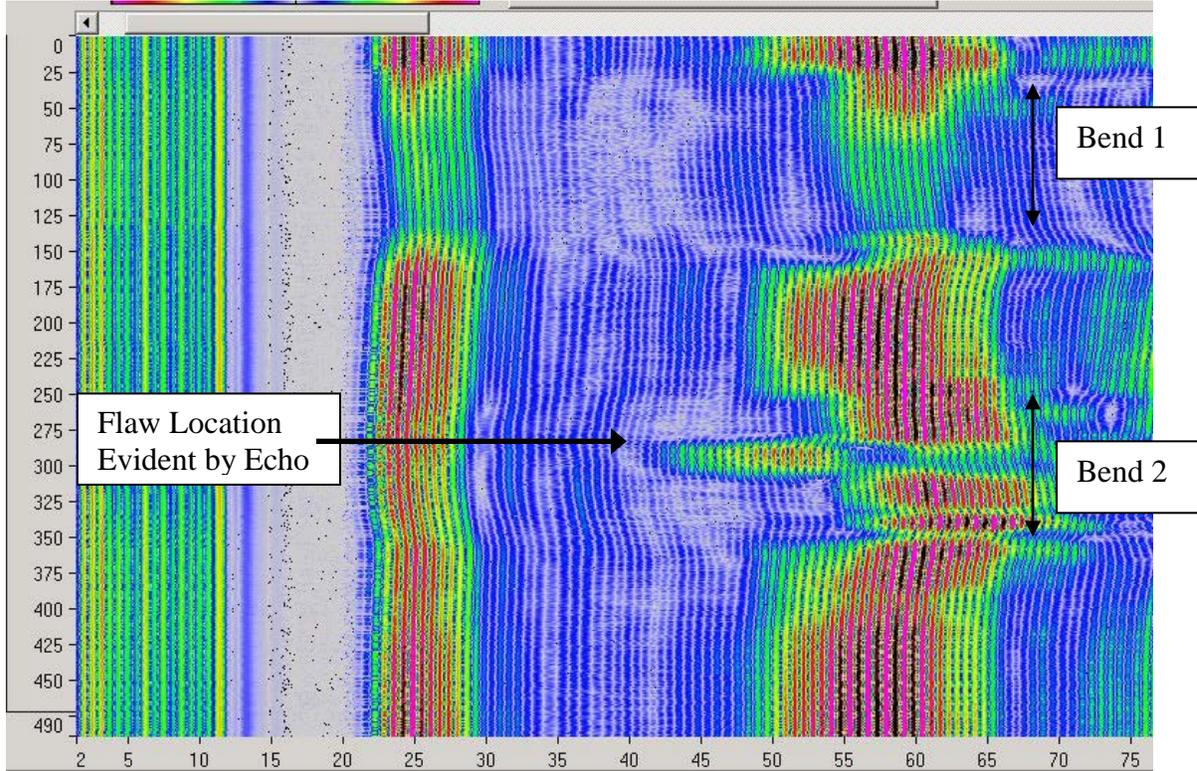


Figure 6: Sample pipe with axial EDM notch.

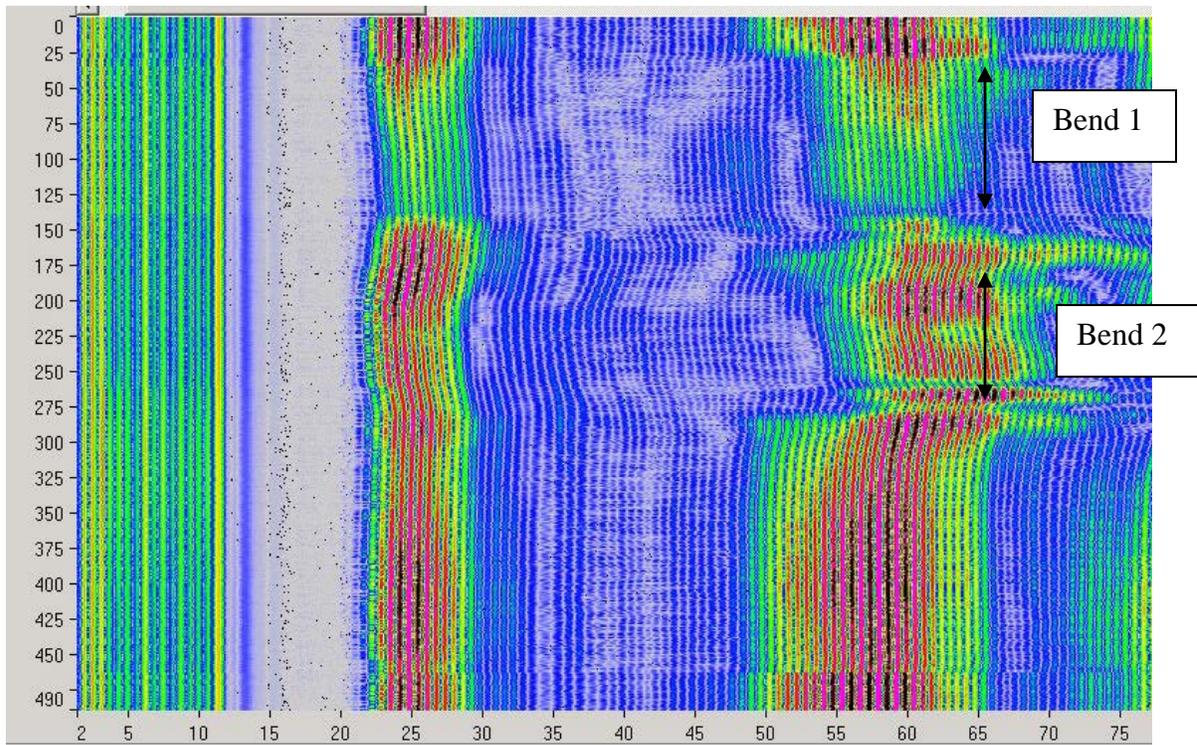
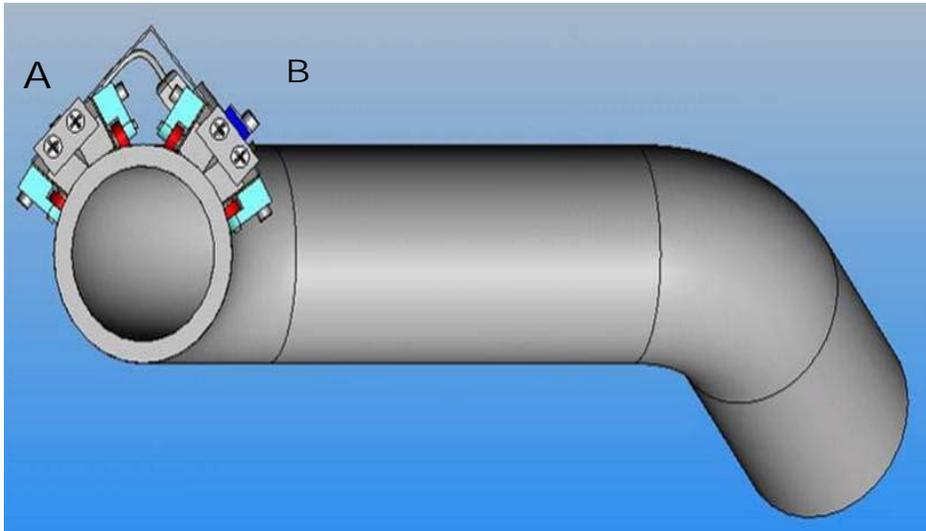


Figure 7: Sample pipe with out cracking, Flaw free specimen. No echo or shadow were present.

**Scan procedure:**

Transducer placement and controlled scanning are essential for accurate results. To ensure encoder traction and minimal transducer lift-off place the transducer in the position indicated in fig. 7 and as illustrated in the included video. The transducer may be dragged along the length of the pipe with the 5mm diameter aluminum rod. A dog leg bend was included in the rod to facilitate the proper navigation of the two bends. The scanning technique was best shown by example in the video.



**Figure 8: Correct placement of transducer position on pipe. Two transducers were delivered with the transmitter and receiver positions reversed to help signal interpretation by changing the arrival time of the echo.**

If an echo appears in a scan or even something that suggests the presence of an echo, the scan can be repeated with the other transducer which swapped transmitter receiver positions. The reciprocal EMAT cart should provide an identical E-Scan image except the echo will occur in a different location in time, thus confirming the presence of an axial crack. Scanning again with the alternately configured transducer has the effect of moving the position of the flaw echo in relation to the other typical recurring signals. This technique is a reliable confirmation for detection of an axial crack.



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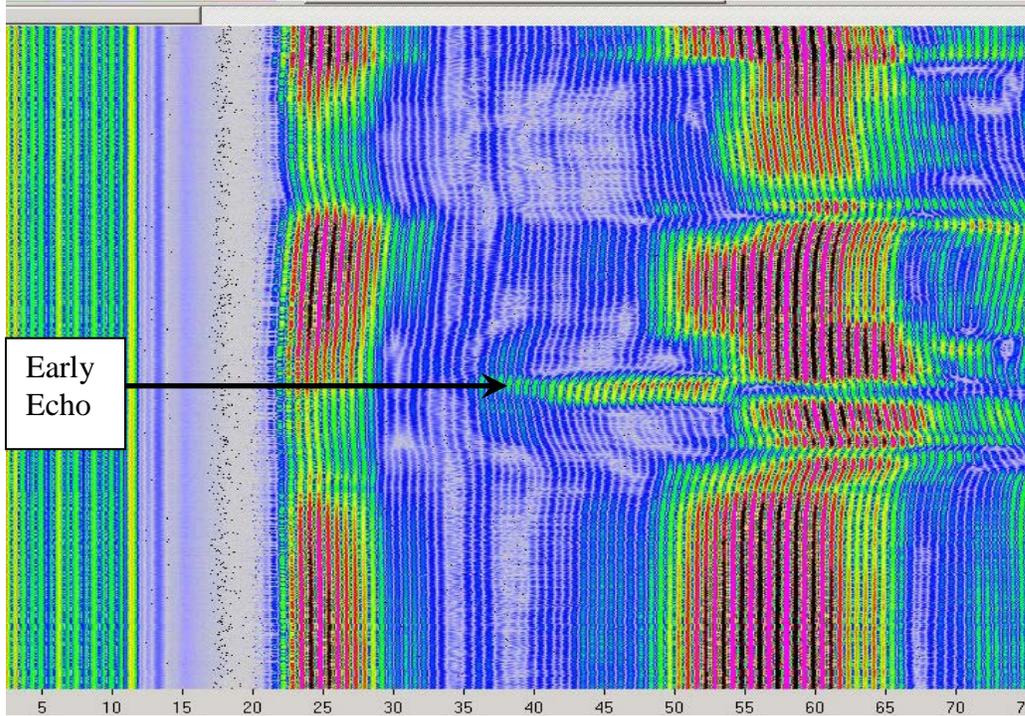


Figure 9: Example of an axial crack echo where the crack was close to the receiver and the echo occurred after the short path signal but before the long path signal.

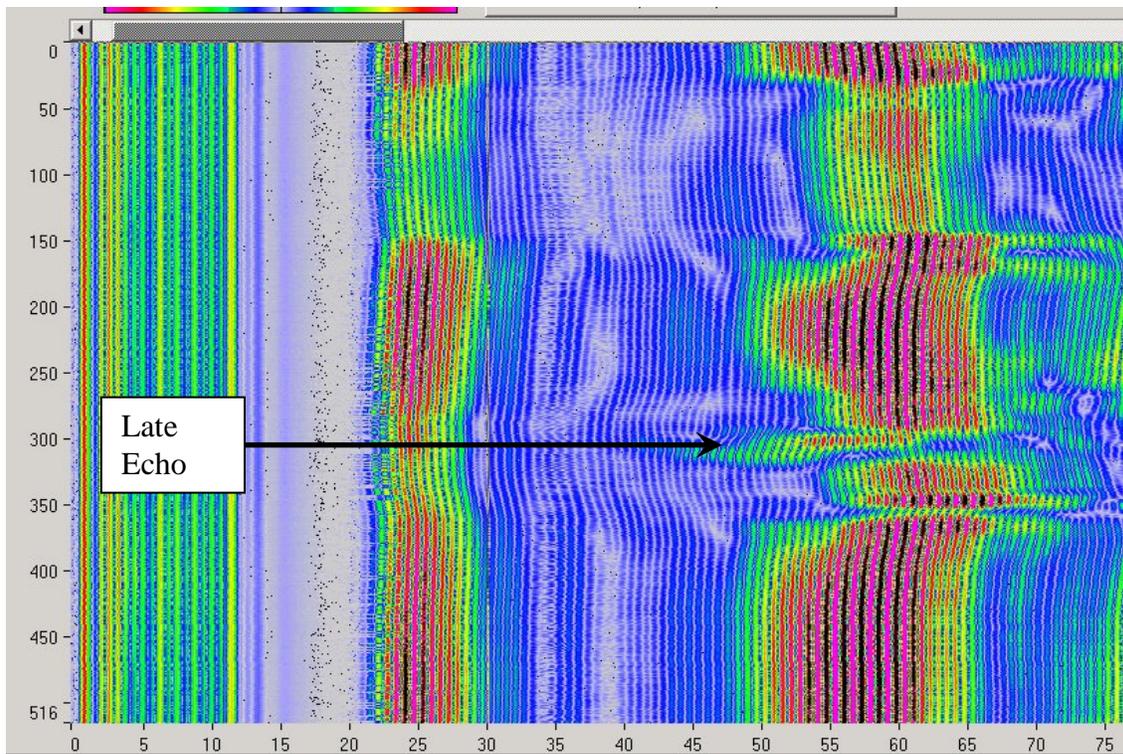


Figure 10: Example of flaw echo interfering with long path signal. This occurs when the axial crack was far from the receiver and occurred at nearly the same time as the long path signal.

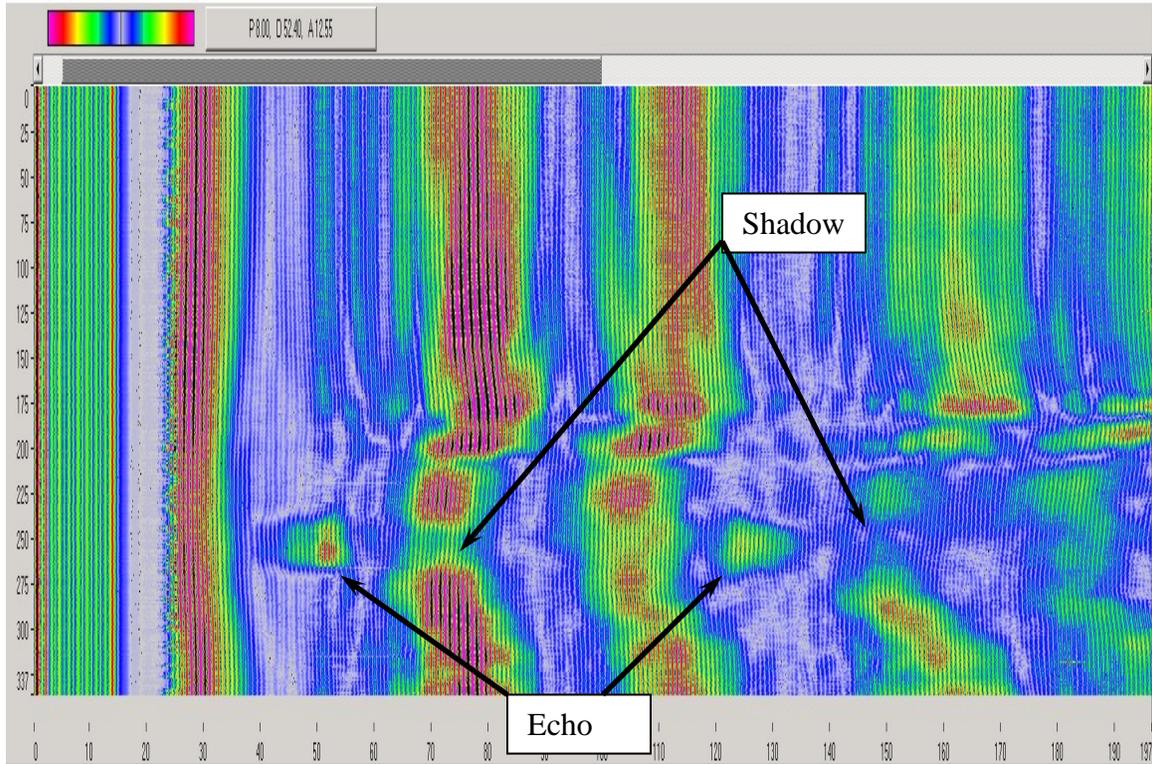


Figure 11: Shadow caused by an axial crack. Note the lack of signal amplitude behind the echo.