ULTRASONIC EVALUATION AND IMAGING OF TUBE CLOSURE WELDS

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INTRODUCTION

Tube closure welds, commonly called pinch welds, are made by solid state upset welding, where quality assurance consists of process control and geometric feature verification. Ultrasonic nondestructive evaluation demonstrated the feasibility for sorting oxide contaminated pinch welds from clean welds. Until now contaminated pinch welds could only be detected by destructive testing. Two approaches are presented in this paper. First, a study was conducted to detect the variation in the ultrasonic signal caused by interaction with the pinch weld. Correlations between the good and bad welds were accomplished with feature extraction and pattern recognition techniques. The second approach involved high resolution scanning of the pinch weld with an acoustic microscope. The acoustic microscope produced excellent color images of the weld which clearly distinguished the pre-weld cleanliness.

WELD SPECIMEN MANUFACTURE

Pinch weld specimens were made for this study by resistance welding 0.125 inch, stainless steel tubing [1]. Poor welds were made by deliberately oxidizing the inside of the tube before welding. The optimal welds were cleaned with an acid etch before welding. A set of nine clean samples and twelve oxidized samples were made for Sandia's study and a set of seven clean samples and nine oxidized samples were evaluated at Ames Laboratory. Data acquired at Ames was subsequently sent to Sandia.

DATA ACQUISITION

Two data acquisition techniques were applied to the evaluation of pinch welds. Sandia National Laboratories developed a through transmission method with a pair of matched 50 MHz contact transducers. These probes have quartz buffer rods machined to fit the curvature of the pinch weld region. A broad band ultrasonic pulse was sent through the weld, digitized with a 500 MHz sampling rate transient analog to digital converter, and stored in a PDP 11/34 minicomputer. The waveforms were manipulated in the computer and predictions were made regarding pinch weld integrity. Ames Laboratory acquired similar data with an immersion, through transmission technique [2]. Their data was acquired with focused 50 MHz transducers, digitized and stored in a computer. The ultrasonic waveforms were copied onto floppy disks and sent to Sandia for testing with the pattern recognition algorithm.

PATTERN RECOGNITION APPROACH

Ultrasonic feature extraction and pattern recognition technology has matured into a powerful tool for correlating acoustic signals with unknown reflectors. This classification procedure involves training the computer to recognize specific characteristics of the ultrasonic waveform and to make predictions based on algorithms developed on known samples. As described in detail in reference [3], there are several distinct steps in this process: acquiring excellent ultrasonic data, processing the signals, extracting appropriate features from the data, developing a classifiation algorithm, and testing the algorithm with unknown data. The result of the process should be a reliable method for evaluating the weld condition.

PATTERN RECOGNITION RESULTS

Two independent data acquisition techniques provided ultrasonic signals for training and testing a pattern recognition algorithm. An algorithm developed with the training data taken at Sandia correctly predicted all the pinch weld samples. Four features and a hyperquadratic discriminant function were necessary to correctly classify the training data (Table I). The hyperquadratic function provides an optimal decision surface in four dimensional space for separating the two weld qualities. The same classification code was implemented on the data acquired at Ames Laboratory and again all the pinch welds were correctly predicted (Table I). As a further refinement, other features and pattern recognition methods were tried on the Ames pinch weld data. Their immersion data was correctly classified with only two features and a simpler two-space cluster diagram (Table I). This technique did not classify the data from Sandia's contact method very well.

ACOUSTIC MICROSCOPE

The second part of this study ultrasonically imaged the pinch weld with a high resolution acoustic microscope. A block diagram of the acoustic microscope is shown in Figure 1. Precise x, y, z motions are done with an Anorad stage which has positioning increments of one micron and a maximum scanning velocity of eight inches per second. Standard high frequency ultrasonic equipment pulsed the transducer and received the reflected signal. For this study, a 30 MHz pulse from the back surface of the pinch was gated, peak detected and digitized for computer acquisition and color image display. Thus, the color coded C-scan display indicated amplitude variations in the reflected signal from the back wall of the pinch weld in this pulse echo mode.

TABLE I. RESULTS OF ANALYZING CONTACT ULTRASONIC DATA (SANDIA) AND IMMERSION ULTRASONIC DATA (AMES)

TECHNIQUE	NO. SAMPLES	FEATURES	RELIABILITY
Contact (Sandia)	9 Clean 12 Oxide	5: Area under video envelope 7: Standard deviation of video envelope 10: Phase at .25 video envelope 25: Skewness of analytic spectrum	100% Hyperquadric Function
Immersion (Ames)	7 Clean 9 Oxide	5, 7, 10, 25	100% Hyperquadric Function
Immersion (Ames)	7 Clean 9 Oxide	19: Standard deviation of frequency spectrum 24: Standard deviation of analytic spectrum	100% Two Space Cluster Diagram

ACOUSTIC MICROSCOPE RESULTS

Pinch welded tubing has a curvature caused by the electrodes which is not favorable for ultrasonic energy propagation. The first attempt to image the pinch weld was done on samples whose curved outer surfaces had been machined flat and parallel. These surfaces provided excellent interfaces for the ultrasound to penetrate. Figures 2a and 2b are black and white copies of color images of the pinch weld back surface reflection. The acoustic energy from the transducer was directed perpendicular to the weld and has passed through the weld interface twice. A large amplitude back-wall reflection may indicate good transmission through the weld interface and thus a good clean weld. Likewise, a low amplitude reflection may be caused by a poor interface blocking the transmission of the acoustic energy. Figure 2a is a good, machined pinch weld with a high amplitude reflection displayed over the entire weld area. In comparison, Figure 2b has a much lower amplitude reflection at the center of the pinch weld which signifies an oxide

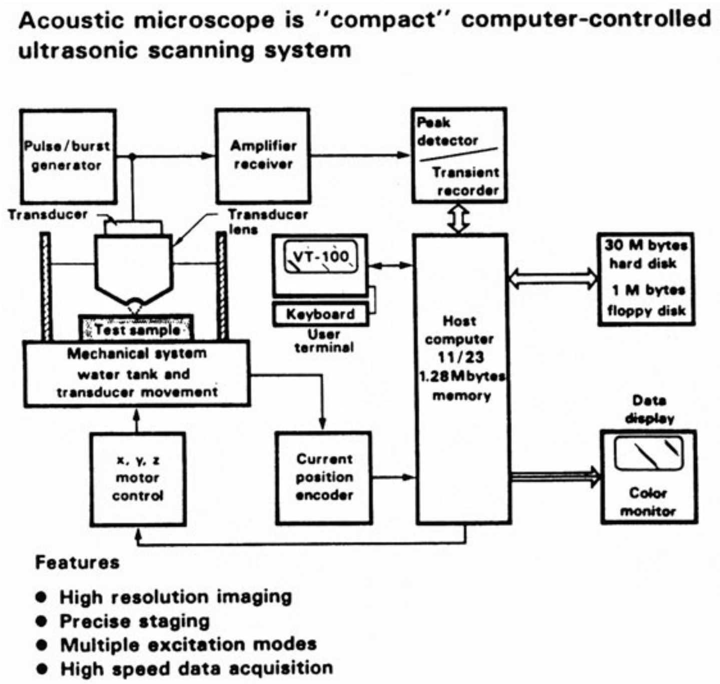


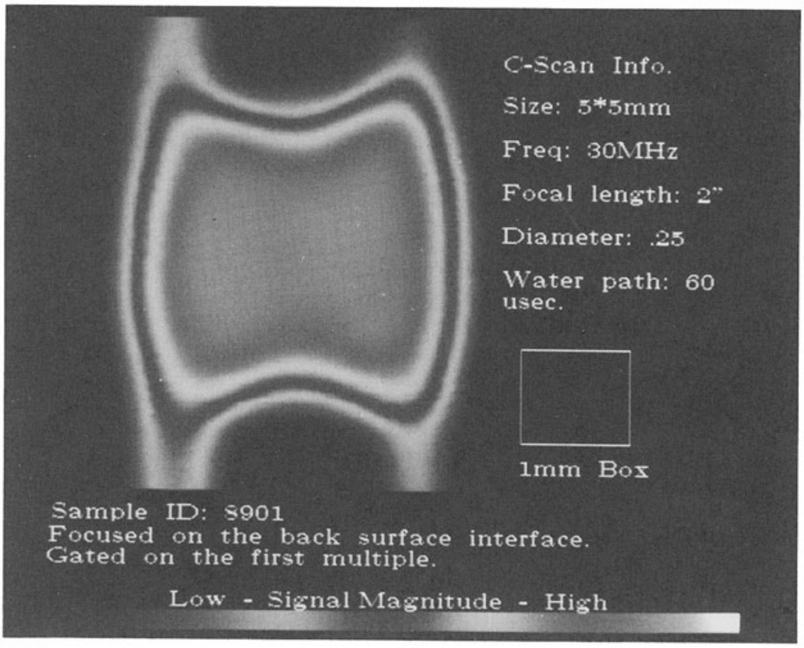
FIGURE 1. BLOCK DIAGRAM OF ACOUSTIC MICROSCOPE

contaminated region. Also in Figure 2b, no reflection is present at either end of the pinch weld which indicates a crack in the oxide contaminated surfaces.

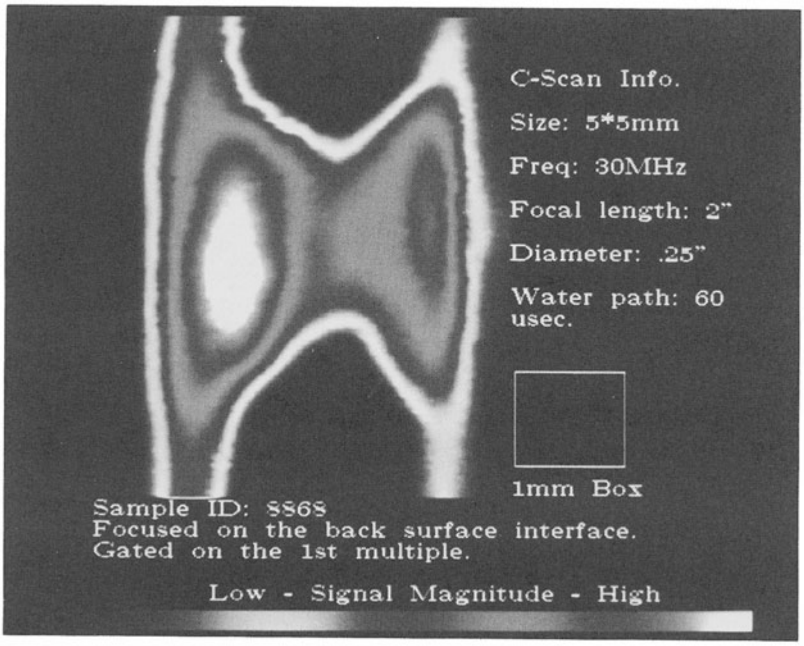
Prompted by the success on the machined pinch welds, the same technique was attempted on as-received samples, which have realistic shapes. Figures 3a and 3b are examples of acoustic microscope scans on curved pinch weld samples. Although the entire weld can not be scanned, imaging the center of the weld may be sufficient to detect oxide contaminated welds. Figure 3a is an image of a good pinch weld and shows high amplitude reflections over the scan area. In contrast, Figure 3b shows a distinct decrease in reflected amplitude at the center of the pinch weld and thus oxide contamination.

SUMMARY

Two ultrasonic methods have demonstrated their ability to detect oxide contamination in pinch welded drawn tubing. The first technique classifies the pinch weld condition by extracting features from the ultrasonic waveforms and implementing a pattern recognition algorithm. This algorithm was developed with contact data taken at Sandia and tested with immersion data from Ames. The pinch welds were correctly classified on both sets of data. Certain characteristics or features of the ultrasonic waveform have shown promise for sorting this two class problem. A better understanding of the mechanisms producing these and possibly other pertinent features is needed. The underlying microstructural cause for the ultrasonic discrimination is still unclear. Although the poor welds had significantly poorer interface quality, as verified by a variety of destructive techniques, the

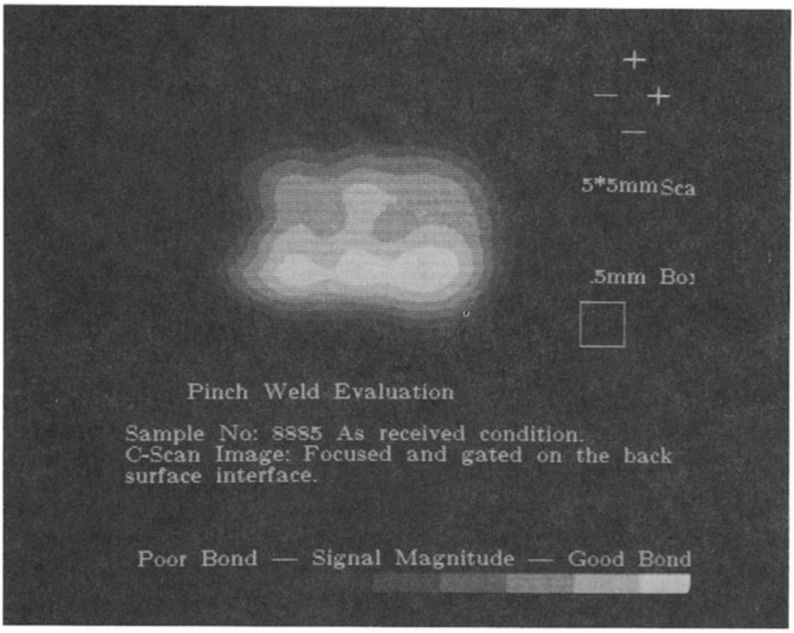


a. Clean



b. Oxide Contaminated

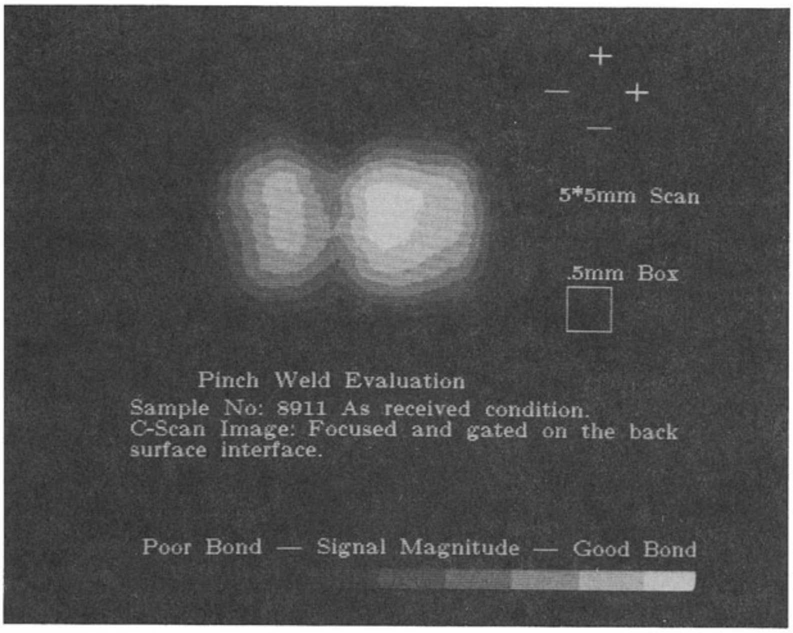
FIGURE 2. ACOUSTIC MICROSCOPE IMAGES OF CLEAN AND OXIDE CONTAMINATED PINCH WELDS. SURFACES WERE MACHINED FLAT AND PARALLEL FOR SCANNING PURPOSES.



Pinch Weld Evaluation

Sample No: 8885 As received condition.
C-Scan Image: Focused and gated on the back surface interface.

a. Clean Pinch Weld



Pinch Weld Evaluation

Sample No: 8911 As received condition.
C-Scan Image: Focused and gated on the back surface interface.

b. Oxidized Pinch Weld

FIGURE 3. ACOUSTIC MICROSCOPE IMAGES OF CLEAN AND OXIDE CONTAMINATED PINCH WELDS IN AS-RECEIVED CONDITION.

presence of oxide may also induce heating and grain size changes between the two classes. These more subtle changes in grain structure may change the ultrasonic attenuation as proposed in (2) and be detected via our discriminant schemes. The second method was to image the pinch weld with an acoustic microscope. Excellent images displaying oxide contamination were produced for both machined and as-received pinch welds.

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