TOFD

Time of Flight Diffraction

The high performance of the Time of Flight Diffraction Technique (TOFD) with regard to the detection capabilities of inherent and service-induced base metal, heat affected zone, and weld defects, such as slag, macrocracking, lack-of-fusion, hot cracking, creep cracking, etc., quickly led to industry acceptance of the technique. Recent revisions of the published guidelines for the inspection and evaluation of high energy seam-welded piping, written and endorsed by the Electric Power Research Institute (EPRI) recognize this technique as a proven ultrasonic examination tool. Since the early 1990s, APTECH has utilized the TOFD technique on many projects, where it was used as a detection and evaluation device along with other more commonly used ultrasonic examination techniques, such as sizing and evaluation by shear wave. The technique provides an efficient, cost-effective baseline data, which enables the future monitoring of critical welds. It also provides the documentation and the precise locations of relevant weld indications for use to establish future lifetime and life expectancy programs. TOFD has the ability to detect and simultaneously size flaws of ALL orientations within the weld and heat affected zone, as explained further. TOFD is recognized as a reliable and proven ultrasonic technique for detection and sizing of critical weld defects in seam-welded high energy piping.

Weld Examination Utilizing TOFD Techniques

An ultrasonic probe is precisely positioned on each side of a weld. One ultrasonic transducer produces or transmits ultrasonic energy, with the other probe functioning as the receiver. The longitudinal sound beam can encounter a weld discontinuity on its path, which would then produce reflected and diffracted signals, (Figures 1 and 2). When the probes are moved parallel along the weld, the resultant waveforms are digitized, stored on hard-disk, and may be printed or displayed as a Grey scale image (Figure 3). The image build up is in effect a through sectional view of the weld examined and can be used for accurate sizing and monitoring of indications (Figure 4).

Figure 1 - Production of Diffraction Signals with TOFD

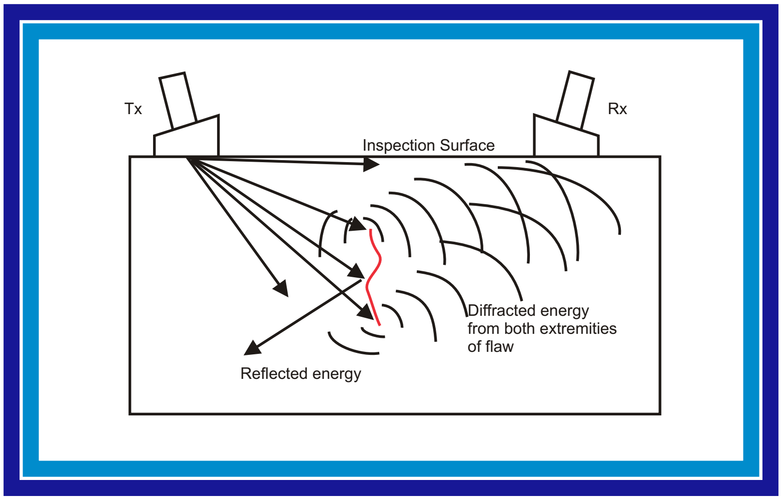


Figure 3 - TOFD Principle

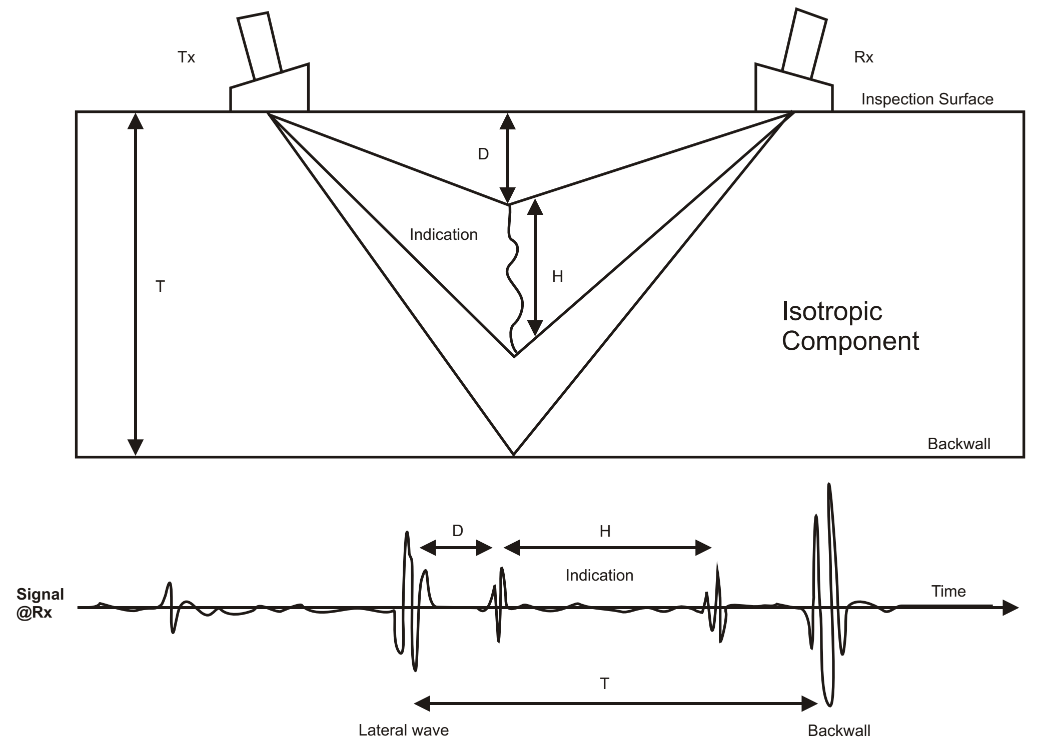
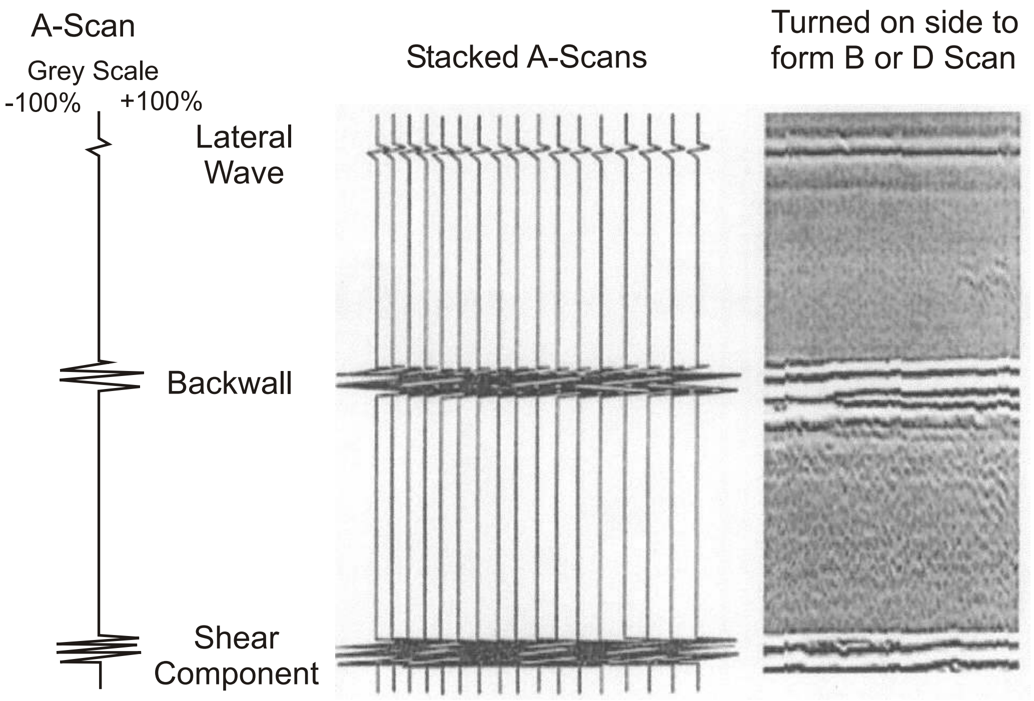
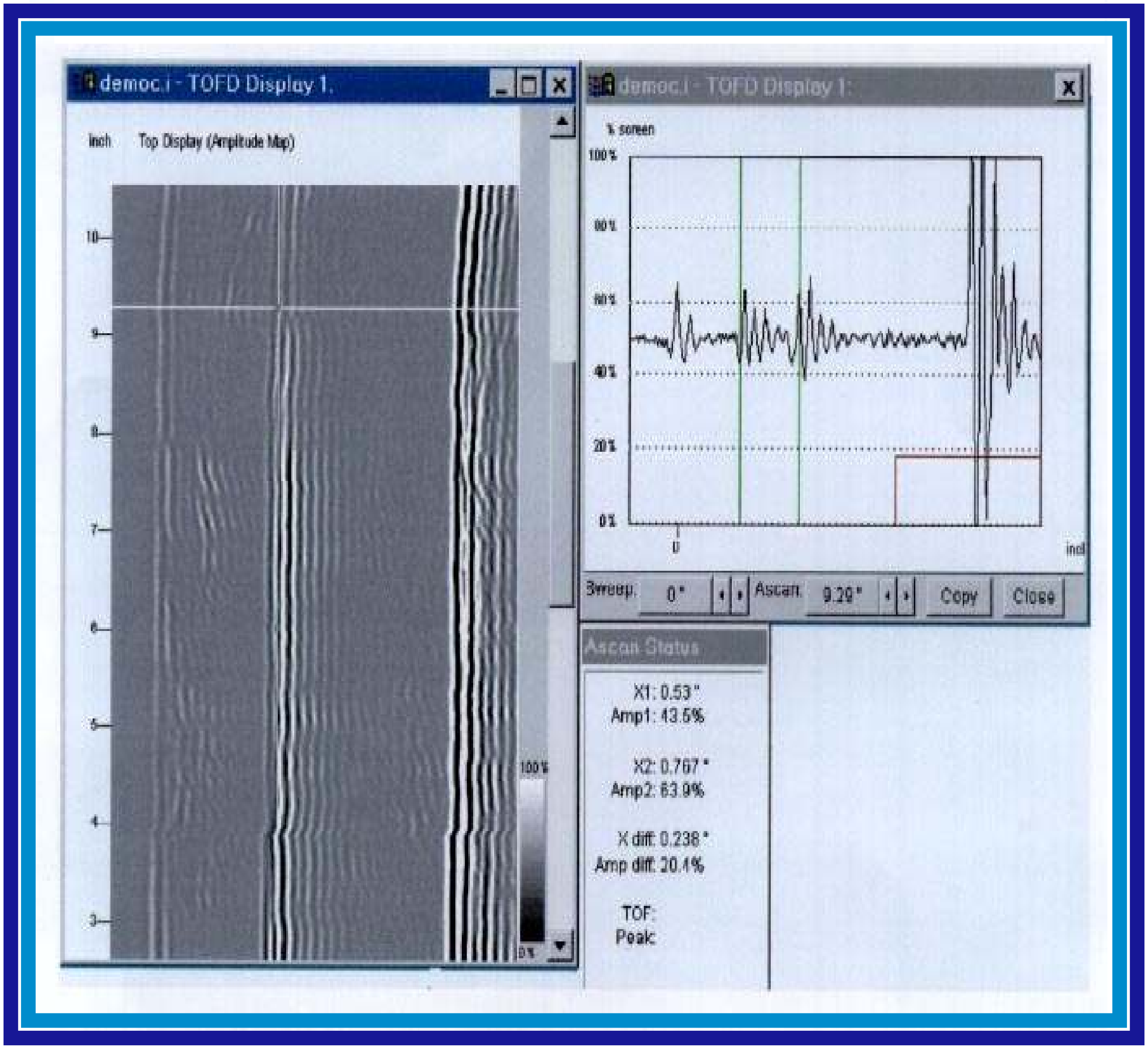


Figure 3 - A-Scan to Grey-Level Plot.



Computer Analysis

Figure 4 - TOFD Data from a Plate Containing a Series of Weld Defects.



Sweep: 0"

Ascan: 9.29"

X1: 0.53"
Amp1: 43.5%

X2: 0.767"
Amp2: 63.9%

X diff: 0.238"
Amp diff: 20.4%

TOF:
Peak:

TOFD Flaw Characterization and Sizing (A Technical Discussion)

The TOFD data acquisition scan normally involves a single scan pass along the volume being examined. A position encoder is used to determine position and to trigger data acquisition at regular intervals along the scan. In this way, with positionally correlated data, flaw length and position within the scan can also be readily accessed. For volumetric inspection, the spacing between adjacent scan passes should be on the order of 1/3 to 1/2 the thickness of the material, the exact value being a function of the transducer spacing as well.

Interaction of the beam with the vertical (i.e., through-wall oriented) planer flaws, either axially or transversely oriented, results in forward scatter **diffracted** energy from both flaw tips, while horizontally oriented and volumetric flaws result in forward **reflected** energy. Hence, flaws from throughout the region of interest of all expected orientations are detected with a single A-scan.

In most cases, flaw characterization and flaw size estimates can be made from a single pass image. Any reflector that has a length parallel to the scan direction will cause a continuous indication over its full length. A single volumetric reflector that has length will give rise to a reflection that is in-phase with the backwall direct L-Wave reflection. An embedded, i.e., midwall crack, produces a unique response in that both tips are detected and displayed simultaneously. These can be identified as such immediately by the phase relationship. The rear tip response, which is in-phase with the backwall, will be 180° out-of-phase relative to the far tip response, which is in phase with the lateral wave. Pairs of linear indications that are radially disposed such that they could otherwise be confused with the two tips of a crack are immediately identified as such because their phases are the same, not reversed. Cracks that are connected to the far surface yield tip response that is in-phase with the backwall standing wave, and they can be identified as being surface-connected by the accompanying disruption in the backwall response. Similarly, cracks that are connected to the test surface yield tip response signatures that are like the far tip on an embedded crack, i.e., out-of-phase with the backwall standing L-wave, with accompanying disruption in the lateral wave. Shallow cracks connected to the test surface may yield only the disruption in the lateral wave, without an identifiable tip response.

Volumetric reflectors having limited extent along the scan direction, i.e., porosity and inclusions, produce characteristic parabolic echodynamic patterns that are immediately and easily recognized in the TOFD image. Transverse cracks, because they appear as point reflectors when the scan is across their minor dimension, yield similar response. To define if an indication giving response typical of a point reflector is truly a point reflector or a transverse crack; the transducers are merely scanned across the flaw in a path perpendicular to the first scan. If it is only a point reflector the resulting echodynamic will be the same regardless of scan direction. If it is a transverse crack, by scanning parallel to its length the continuous nature of the crack in the transverse direction can be defined. Location of the signal source across the width of the volume can be similarly defined by performing a transverse scan at the flaw location.

Because the size estimate and flaw classification is based on the nature of the response and the position of the response source, sensitivity has no effect on the outcome. The positional information and the phase relationships are maintained regardless of sensitivity; consequently, analysis yields the same result. This feature is contrary to acceptable practice for conventional ultrasonic shear wave examinations, in which sensitivity is critically important because the size estimates are based upon some characteristic of the amplitude response envelope, either the peak amplitude or the width of the response envelope at some amplitude relative to the peak. The well-documented, researched and field-proven accuracy of sizing and reproducibility of the measurement have a twofold benefit. First, the inherent accuracy of measurement (through-wall sizing accuracies of +/- 0.02-inch or even better under optimum conditions are attainable) results in high confidence sizing information and low tolerance values for fracture mechanics calculations. Second, the examination reproducibility facilitates accurate periodic trend analysis, as the flaw propagation behavior can be readily monitored over time.