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The Use of Phased Array UT Inspection of OCTG

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Abstract

This paper covers the use of Ultrasonic (UT) Phased Arrays for the automated full length ultrasonic inspection of tubular goods. The technology provides increased flexibility to adapt to varying defect locations, shapes and orientations. Demanding inspection parameters can be optimized for tubulars such as those used in High Pressure/High Temperature Sour Wells.

Introduction

The American Petroleum Industry (API) provides standards for the manufacture and performance properties of pipes and tubes used by the petroleum and natural gas industries. Included in these standards, for both seamless and welded products, are minimum requirements to address inspection for longitudinal (zero degrees to pipe axis), transverse (90 degrees to pipe axis) wall thickness and dimensional defects. Inspection for other defect orientations (oblique oriented defects) are related to the manufacturing process and specific use requirements.

Specifications vary according to performance requirements, company philosophy and associated risk. Requirements are different for a 600 feet depth land well and a 25,000 feet depth offshore well. New opportunities often present challenges which require different or more stringent performance criteria and/or new technologies. To capitalize on these opportunities and address these challenges, major oil companies supplement standards with additional requirements to address specific needs.

Supplementary specification examples may include inspection for oblique defects and laminations which may become detrimental in certain environments or the profiling of diameter and wall data to calculate more exact tubular performance and relative placement in the well.

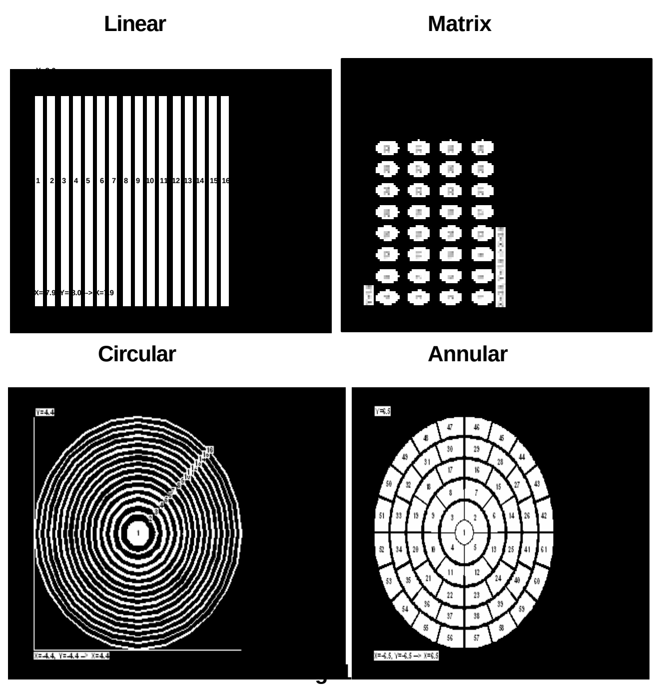
A new technology to the OCTG and Line pipe manufacturers is UT Phased Arrays.

Technology

UT phased arrays consist of a series of individual elements, each with their own connector, time delay circuit, and an analogue to digital converter. Elements are acoustically insulated from each other and are pulsed in groups with pre-calculated time delays for each element, i.e. “phasing”.

Array Probes

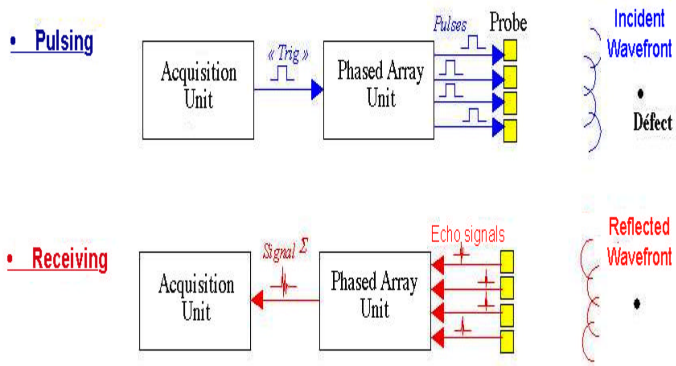
Typical array designs are Linear, Matrix, Circular and Annular (fig.1). Custom probe shapes and designs may be specifically built for specific applications. Linear arrays are the most common type and are fabricated with a single row or matrix.of elements. They are the most economical and widely used for the inspection of OCTG. Matrix arrays are used to scan in two dimensions and provide additional flexibility.



Instrumentation

Instrumentation may be tailored for specific applications. Various configurations include as a minimum, an ultrasonic channel with circuitry for time delay beam forming and data acquisition.

Instrumentation nomenclature such as 32/128 refers to an instrument with 32 multiplexed pulsers and a total of 128 ultrasonic channels. Many instruments may be used in parallel to increase the number of active elements for certain applications.



Phased Array Diagram
Fig. 2

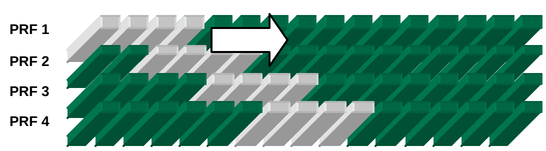
Features

Phased array provides a programmable means for electronic scanning and realtime control of three important UT probe parameters; Focal distance, Beam angle and Beam size.

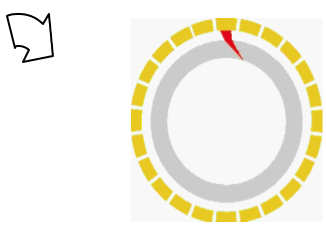
Electronic Scanning

Electronic scanning is moving the beam along one axis of an array without any mechanical movement. This movement is performed by time multiplexing the active elements along the probe geometry. Electronic scanning facilitates rapid scanning of components with constant geometry, e.g. tubes and pipes.

Linear scanning for tubes may be implemented either laterally (fig.3) or circumferentially (fig.4).

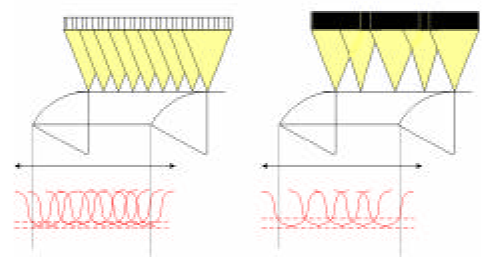


Lateral Scanning of active elements
Fig. 3



Circumferential Scanning of beam around Tube
Fig. 4

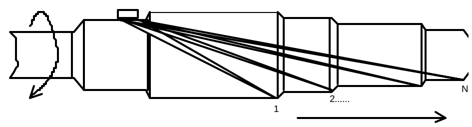
The electronic scanning overlap is adjustable between acoustic apertures and can be optimized to meet or exceed specified repeatability requirements. The repeatability expectations are directly related to inspection coverage density and the peaks and valleys of the relative amplitude response.



Adjustable overlap to address repeatability requirements
Fig. 5

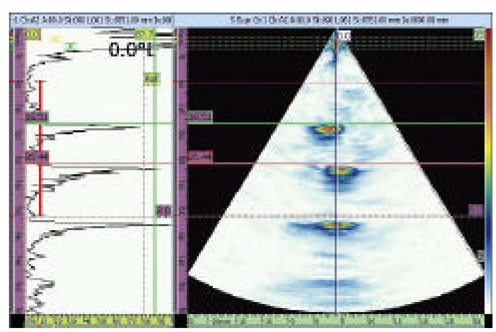
Sectorial scanning

Sectorial scanning is the scanning of a complete section of a volume without probe movement. Sectorial scanning is useful for the inspection of complex geometry's such as accessories, equipment and welds. This feature combines the advantages of multiple conventional probes in a single phased array probe (fig.6).
By changing the incident angle between apertures a variety of inspections can be performed without changing the position of the probe.

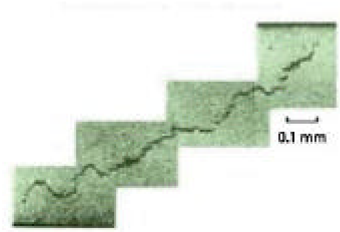


Inspection of complex geometry with a single Phased Array Probe
Fig. 6

Sectorial scanning from -30 to +30 degrees (fig.7) allows the user to distinguish between spot indications and interconnected defects such as stress oriented hydrogen sulphide cracking (SOHIC) (fig.8).



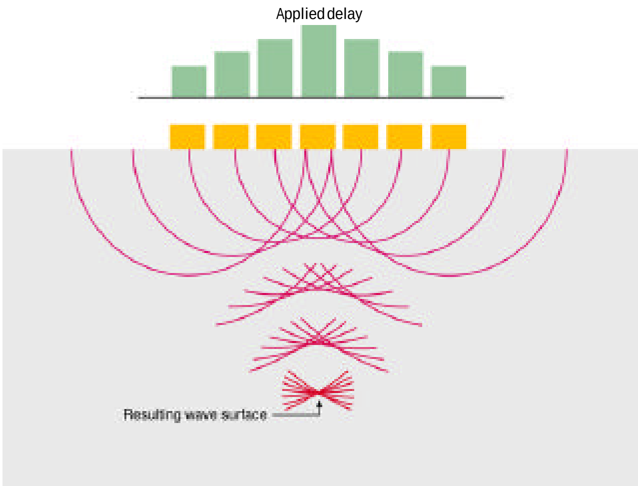
Sectorial Scan Display of SOHIC defect
Fig. 7



SOHIC micrograph
Fig. 8

Beam Focusing

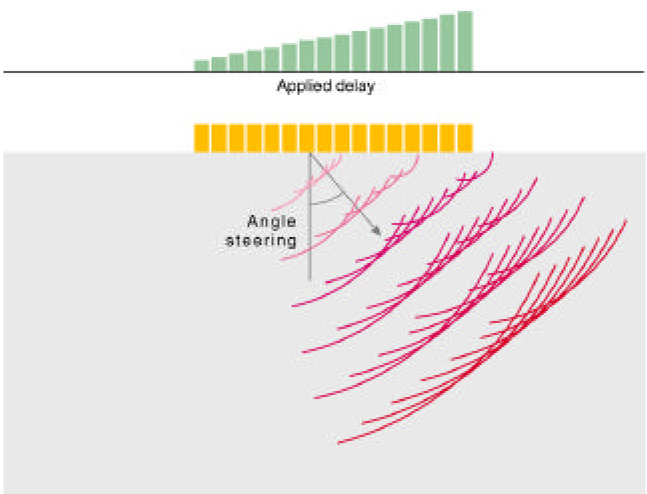
Beam focusing is achieved by applying symmetricall time delays to the element firing order (e.g. parabolic) relative to the element position (Fig.9).



Symmetrical time delayed firing of elements to focus beam
Fig. 9

Beam Steering

Beam steering is achieved by applying asymmetrical (e.g. linear) time delays to the element firing order (fig.10). Beam steering provides the flexibility for multiple angle inspections, using a single probe. Different focal laws can be used to generate both compression and shear waves with the same probe.



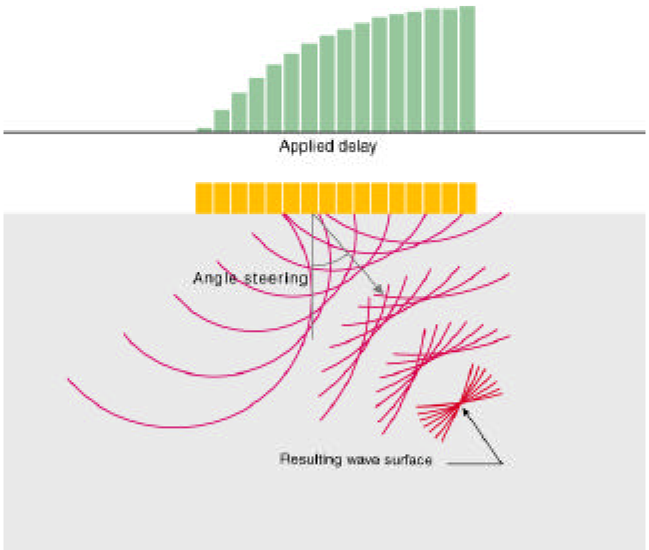
Asymmetrical time delayed firing of elements to steer beam
Fig. 10

Beam Size and Shape

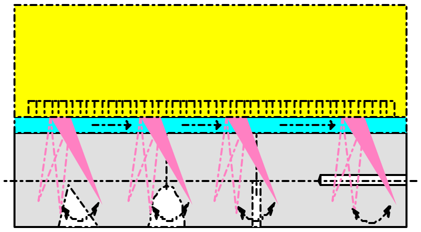
The beam size and shape are determined by the element characteristics and properties, number of elements used for the beam aperture and the applied focus parameters.

Combining Specific Features

Features are often combined to optimize inspection variables associated with different pipe inspection parameters (fig. 11 & 12).



Focusing and Steering Combination
Fig. 11



Steering and Scanning Combination
Fig. 12

OCTG applications

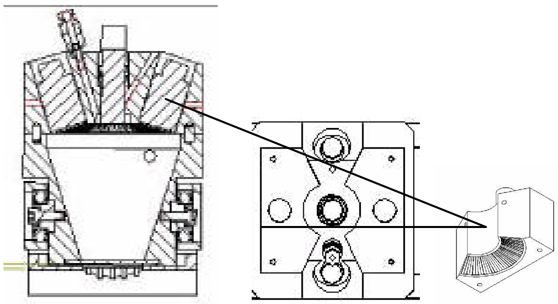
A variety of Phased Array Inspection Systems are available to satisfy industry needs. These systems include circular arrays, conical arrays and axial arrays which are used to measure wall thickness and detect laminar, longitudinal, transverse and oblique defects. They often incorporate specific features such as electronic scanning; beam steering, beam focusing and multi-angle display software.

Phased Arrays are being used for the inspection of casing and tubing, drill pipe and drill string components, line-pipe and coiled tubulars. Manufacturing processes include seamless and electric resistance, sub-merged and laser welded products. Their programmable features provide for the optimization of specific inspection parameters which make Phased Arrays a good candidate for HPHT tubulars.

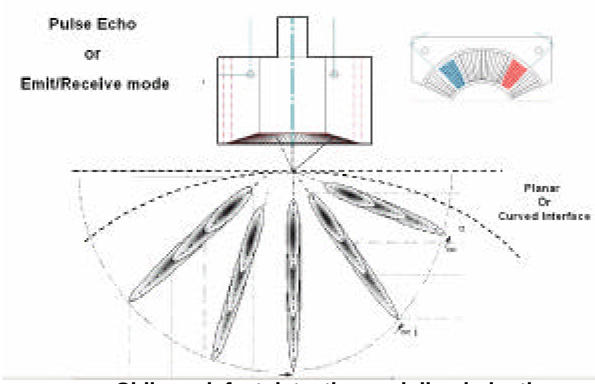
Conical Array Cluster

The Conical Array Cluster consists of two phased array probes, a coupling column and a shoe with wear plate to match the diameter of the pipe (fig.13). Linear scanning is used to provide inspection of the complete angular sector of the pipe covered by array probe.

Defect orientation is easily discernible by monitoring those apertures (group of elements to form the beam) with the greatest response (Fig.14).



Conical Array Cluster
Fig. 13

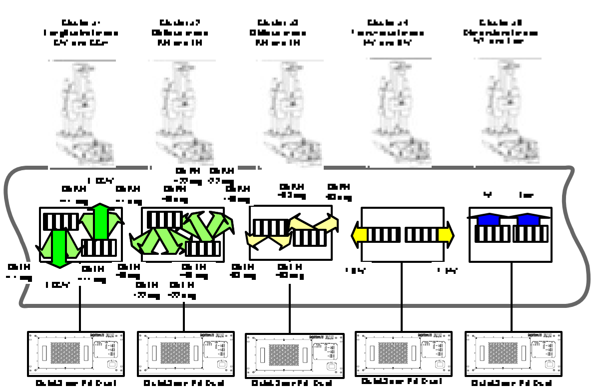


Oblique defect detection and discrimination
Fig. 14

Axial Array Clusters

The axial array cluster consists of two simple linear array probes with preset incident angles in a shoe, a coupling column and a wear plate to match the diameter of the pipe.

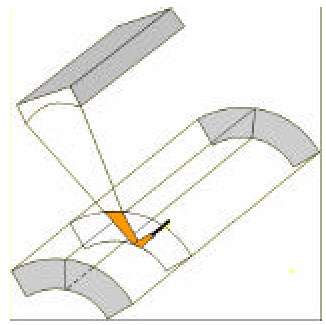
The array probes can be used for multiple defect orientations by generating compound angles between the fixed incident and steered programmable angles (Fig. 15).



Typical Axial Array Cluster System configuration
Fig. 15

Longitudinal Defect Detection

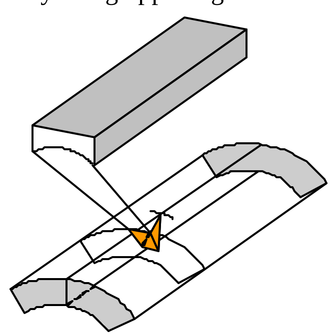
The array probe is oriented with a predetermined fixed incident angle to generate the desired shear wave in steel (Fig. 16). The aperture length is programmed by selecting the number of elements used to form the aperture. The array is mechanically focussed parallel to the axis of the pipe to concentrate the sound energy on the surface of the pipe and reducing the scatter due to the curved surface. One probe is used for inspection in the clockwise direction and a second probe is used for inspection in the counter-clockwise direction.



Longitudinal defect Detection
Fig. 16

Transverse Defect Detection

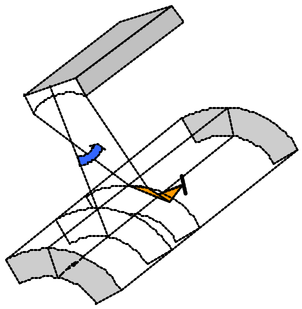
The single array probe is parallel to the axis of the pipe with no incident angle (fig. 17). The aperture size and incident angle is programmed by selecting the number of elements used to form the beam and the desired steering angle. The same probe array is used for inspection in both the leading and trailing directions by using opposing focal laws.



Transverse Defect Detection
Fig. 17

Oblique oriented Defect Detection

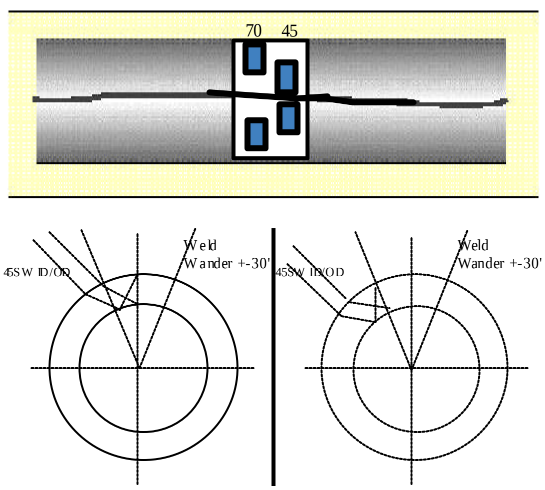
The array probe is axially oriented to the pipe surface with a fixed incident angle relative to the y-axis and a second angle is created by electronically steering the beam along the x-axis to form a compound incident angle (fig.18). The resultant refracted oblique beam is used for the detection of an oblique defect. The compound angles can be varied to create specific oblique angles. Additionally in this example the beam is manually focussed along the axis of the pipe to optimize sound energy on the surface.



Oblique Defect Detection
Fig. 18

Weld-line Inspection Arrays

Electronic scanning of the beam over the weld sector is used to inspect weld lines with specified wander while maintaining calibrated response from weld flaws. Scanning with a compression wave 90 degrees to the weld is also used to provide a profile of the weld area trim. Beam steering or sector scanning can be used to produce multiple inspection angles to optimize the inspection for anticipated defects.



Electronic Scanning to provide inspection of the weld with movement from +30 degree to -30 degree
Fig. 19

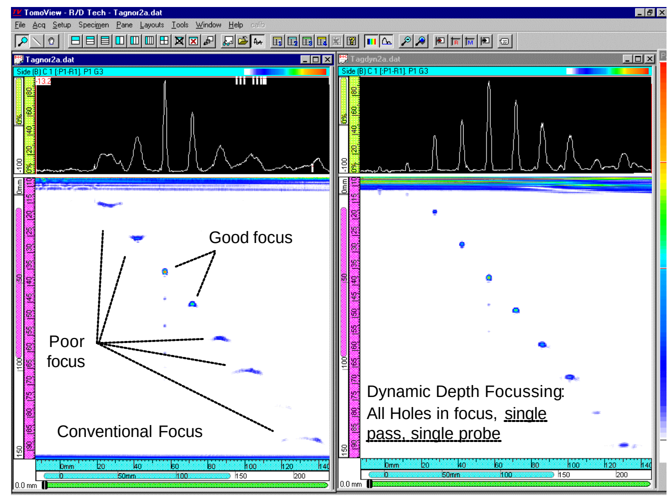
Curved Probe for Electronic scanning of weld area
Fig. 20

Defect Sizing and Interpretation

Phased Array inspection lends itself to all proven conventional means of defect sizing including amplitude comparison, dB drop, time of flight diffraction and zone discrimination methods.

Dynamic Depth Focusing

Dynamic depth focusing uses a series of programmable delays and apertures (focal laws) to provide for focusing at several depths using a single probe (fig.21). A single pulse provides examination throughout the full depth of the wall thickness with near-optimal focus. A single probe with Dynamic Depth focusing can replace many probes with different focal lengths.



Comparison of probe with Dynamic Depth Focusing
Fig. 21

Summary

Phased Arrays are flexible and can be used to match inspection performance and product requirements such as;

- Sensitivity to small defects by optimizing the beam dimensions and shape to the anticipated defects
- Adaptability of the beam coverage and inspection overlap to specified requirements
- Optimization of the focal length and spot size for wall thickness and geometry
- Programmable Beam Steering to maximize detection of both surface breaking and non-surface breaking defects.
- Multiple inspection angles (sector scan) from a single probe
- Defect interpretation using multiple angle correlations
- Flaw sizing features including amplitude comparison, zone discrimination, dB drop and time of flight diffraction methods
- Electronic scanning minimizes the need for moving mechanical parts and hand scanning.
- Dynamic depth focusing with multiple focal zones for heavy wall products

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