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Ultrasonic Phased Array[1]

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Ultrasonic phased arrays use multiple ultrasonic elements and electronic time delays to generate and receive ultrasound, creating beams by constructive and destructive interference. As such, phased arrays offer significant technical advantages over conventional single-probe ultrasonic testing: the phased array beams can be steered, scanned, swept and focused electronically.

Electronic scanning permits very rapid coverage of the components, typically an order of magnitude faster than a single-probe mechanical system. Speed increases like this can be highly cost-effective.

Beam forming permits the selected beam angles to be optimized ultrasonically by orienting them perpendicular to the discontinuities of interest — for example, lack of fusion in welds.

Beam steering (usually called sectorial scanning) can be used for mapping components at appropriate angles to optimize probability of detection. Sectorial scanning is also useful for inspections where only a minimal footprint is possible.

Electronic focusing permits optimizing the beam shape and size at the expected discontinuity location, as well as optimizing probability of detection. Focusing improves signal-to-noise ratio significantly, which also permits operating at lower pulser voltages.

Overall, phased arrays optimize discontinuity detection while minimizing test time.

Operation

Ultrasonic phased arrays are similar in principle to phased array radar, sonar and other wave physics applications. However, ultrasonic development is behind the other applications because of a smaller market, shorter wavelengths, mode conversions and more complex components. Industrial applications of ultrasonic phased arrays have increased in the twenty-first century.

Phased arrays use an array of elements, all individually wired, pulsed and time shifted. These elements can be a linear array, a two-dimensional matrix array, a circular array or some more complex form (Fig. 1). Most applications use linear arrays, because these are the easiest to program and are significantly cheaper than more complex arrays because of fewer elements. As costs decline and experience increases, greater use of the more complex arrays can be predicted.

The elements are ultrasonically isolated from each other and

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packaged in normal probe housings. The cabling usually consists of a bundle of well shielded micro coaxial cables. Commercial multiple-channel connectors are used with the instrument cabling.

Each element generates a beam when pulsed; multiple beams constructively and destructively interfere to form a wave front. (This interference can be seen, for example, with photoelastic imaging.)[2] The phased array instrumentation pulses the individual channels with time delays as specified to form a pre-calculated wave front. For receiving, the instrumentation effectively performs the reverse, that is to say, it receives with precalculated time delays, then sums the time shifted signal and displays it. This is shown in Fig. 2.

The summed waveform is effectively identical to a single-channel discontinuity detector using a probe with the same angle, frequency, focusing, aperture and other settings. Figure 2 shows typical time delays for a focused normal beam and transverse wave. Sample scan patterns are shown in Fig. 3 and are discussed below.

Implementation. From a practical viewpoint, ultrasonic phased arrays are primarily a means of generating and

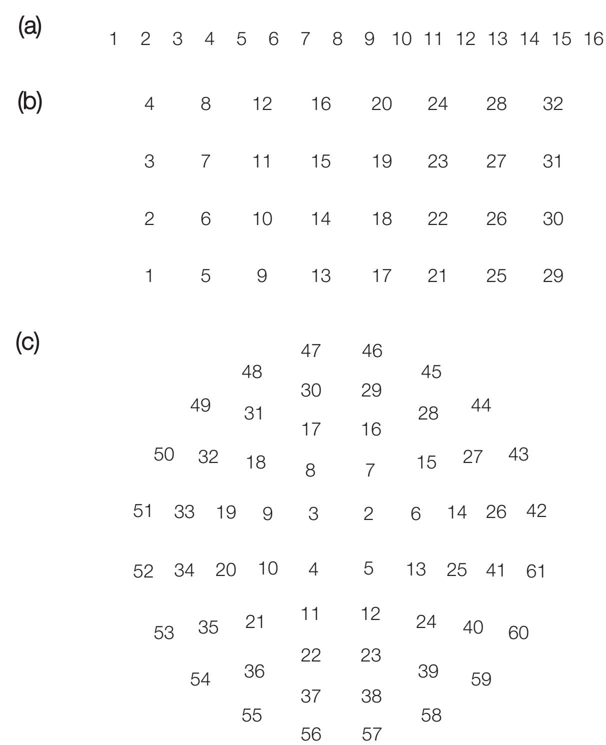

Figure 1. Array types: (a) one-dimensional linear array of 16 sensors; (b) two-dimensional matrix array of 32 sensors; (c) sectorial annular array of 61 sensors.

receiving ultrasound; once the ultrasound is in the material, it is independent of generation method, whether generated by piezoelectric, electromagnetic, laser or phased arrays. Consequently, many of the details of ultrasonic testing remain unchanged; for example, if 5 MHz is the optimum test frequency with conventional ultrasonic testing, then phased arrays would typically start by using the same frequency, aperture size, focal length and incident angle.

Besides generating and receiving mulitple waveforms, phased arrays are good at imaging. Specifically, a standard display shows a two dimensional B- or S-scan while additional C-scans can be provided.

While phased arrays require well developed instrumentation, one of the key requirements is good, user-friendly software. Besides calculating the focal laws, the software saves and displays the results, so good data manipulation is essential. As phased arrays offer considerable application flexibility, software versatility is highly desirable. Phased array inspections can be manual, semiautomated (that is, encoded but hand-propelled) or fully automated, depending on the application, speed, budget and other considerations.

Although it can be time consuming to prepare the first setup, the information is recorded in a file and only takes seconds to reload. Also, modifying a prepared setup is quick in comparison with physically adjusting conventional probes.

Scan Types

Electronic pulsing and receiving provide significant opportunities for a variety of scan patterns (Fig. 3).

Electronic Scans. Electronic scans are performed by multiplexing the same focal law (time delays) along an array (Fig. 4). Typical arrays have up to 128 elements. Electronic scanning permits rapid coverage with a tight focal spot. If the array is flat and linear, then the scan pattern is a simple B-scan. If the array is curved, then the scan pattern will be curved. Electronic scans are straightforward to program. For example, a phased array can be readily programmed to perform corrosion mapping, or to test a weld using 45 deg and 60 deg transverse waves, which mimics conventional manualinspections.

Sectorial Scans (S-Scans). Sectorial scanning is unique to phased arrays. Sectorial scans use the same set of elements but alter the time delays to sweep the beam through a series of angles (Fig. 5). Again, this is a straightforward scan to program. Applications for sectorial scanning typically involve a stationary array, sweeping across a relatively inaccessible component like a turbine blade root, to map out the features and discontinuities. Depending primarily on the array frequency and element spacing, the sweep angles can vary from ±20 deg up to ±80 deg.

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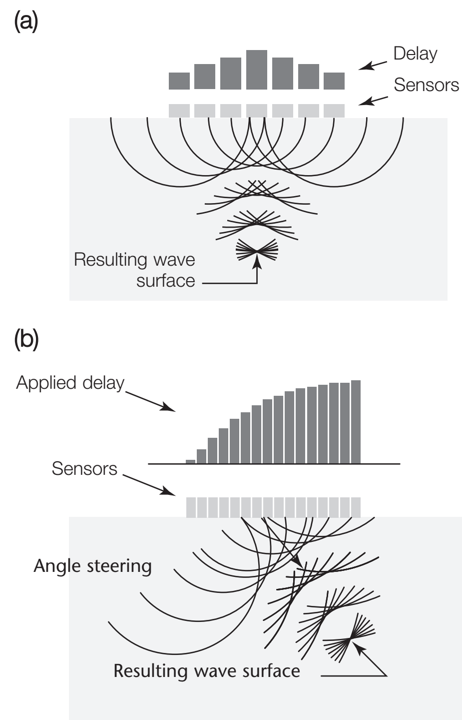

Figure 3. Schematic time delays (histograms): (a) focused normal beam; (b) focused transverse wave.

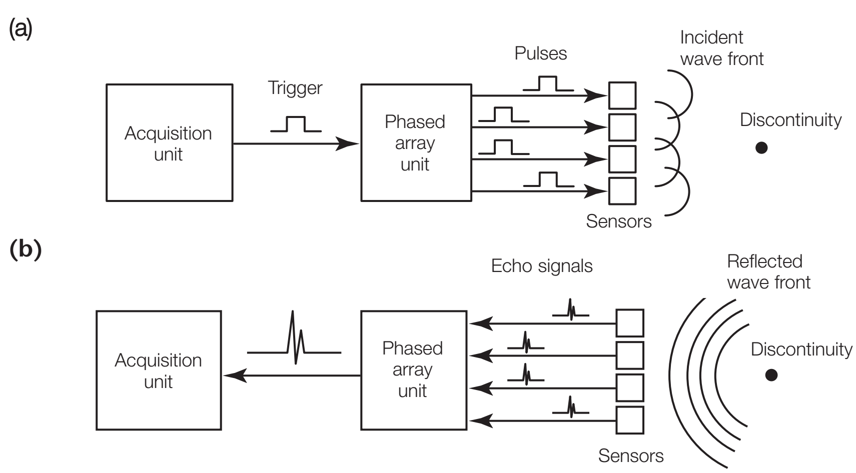

Figure 2. Beam: (a) emitting; (b) receiving.

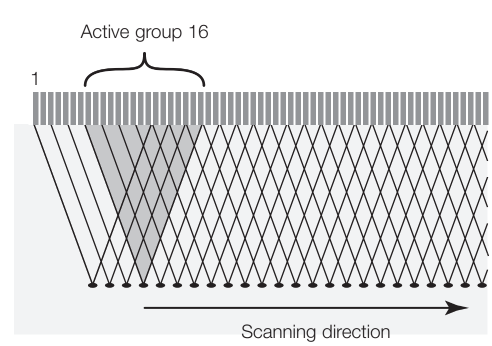

Figure 4. Electronic scanning.

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Combined Scans. Combining linear scanning, sectorial scanning and precision focusing leads to a practical combination of displays (Fig. 6). Optimum angles can be selected for welds and other components whereas electronic scanning permits fast and functional tests. For example, combining linear and longitudinal wave sectorial scanning permits full ultrasonic testing of components over a given angle range, such as ±20 deg. This type of test is useful when simple normal beam tests are inadequate, such as titanium castings in aerospace where discontinuities can have random orientations. A related approach applies to weld inspections, where specific angles are often required for weld geometries; for these applications, specific beam angles are programmed for specific weld bevel angles at specific locations.

Linear Scanning of Welds. Manual ultrasonic weld inspections are performed using a single probe, which the operator rasters back and forth to cover the weld area. Many automated weld test systems use a similar approach (Fig. 7a), with a single probe scanned back and forth over the weld area. Rastering is time consuming because the system has dead zones at the start and finish of the raster.

In contrast, most multiple-probe systems and phased arrays use a linear scanning approach (Fig. 7b). Here the probe is scanned linearly round or along the weld, while each probe sweeps out a specific area of the weld. The simplest approach to linear scanning is found in pipe mills, where a limited number of probes test electric resistance welded pipe.

Phased arrays for linear weld tests operate on the same principle as the multiprobe approach; however, phased arrays offer considerably greater flexibility than conventional automated ultrasonic testing. Typically, it is much easier to change the setup electronically, either by modifying the setup or reloading another; often it is possible to use many more beams (equivalent to individual conventional probes) with phased arrays; special inspections can be implemented simply by loading a setup file.

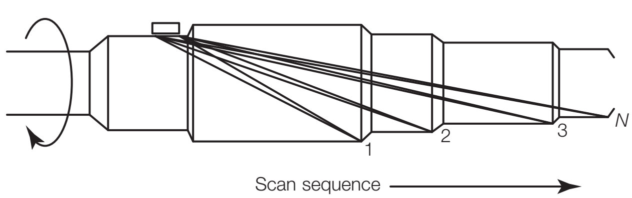

Figure 5. Sectorial scanning on turbine rotor for sequence of *N* scans.

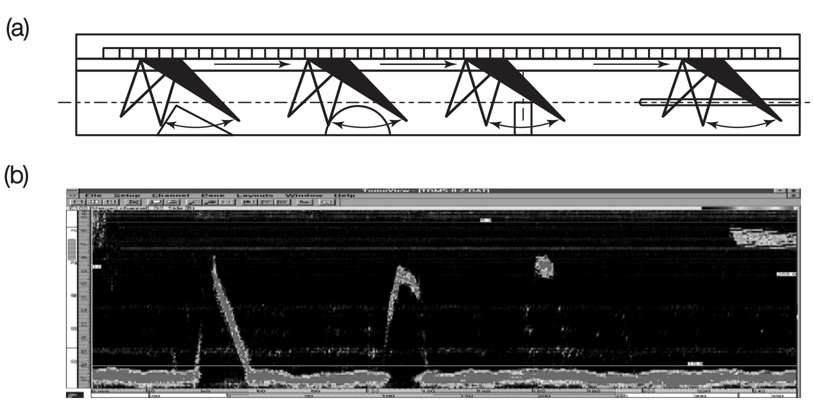

Figure 6. Phased array imaging patterns: (a) scanning pattern using sectorial and linear scanning; (b) image using all data merged together.

Applications

Ultrasonic phased arrays are flexible and can address many types of problems. Consequently, they are used in a wide variety of industries where the technology has inherent advantages. These industries include aerospace, nuclear power, steel mills, pipe mills, petrochemical plants, pipeline construction, general manufacturing and construction, plus a selection of special applications. All these applications take advantage of one or more of the dominant features of phased arrays:

1. Speed — scanning with phased arrays is much faster than single probe conventional mechanical systems, with better coverage.
2. Flexibility — setups can be changed in a few minutes, and typically a lot more component dimensional flexibility is available.
3. Cost effective — particularly for high volume inspections.
4. Small footprint — small matrix arrays can give significantly more flexibility for testing restricted areas than conventional probes.
5. Imaging — an image (enhanced to simulate three dimensions) of discontinuities is much easier to interpret than a waveform. The data can be saved and redisplayed as needed.

Each feature generates its own applications. For example, speed is important for pipe mills and pipelines, plus some high volume applications. Flexibility is important in pressure vessels and pipeline welds due to geometry changes. Test angle is key for pipelines, some pressure vessel and nuclear applications. Small footprint is applicable to some turbine applications. Imaging is useful for weld tests.

Phased array nondestructive testing is still quite new and still requires some setup effort, especially for complex three-dimensional applications. Two-dimensional setups are generally straightforward, provided the software is user friendly. For example, automated setup procedures have been developed for weld tests. Phased array systems are sometimes more costly than single-channel systems; however, the higher speed/productivity, data storage and display, smaller footprint and greater flexibility often offset the higher costs, especially with the newer portable instruments.

Lastly, the biggest practical problem is finding trained operators, and several companies have developed appropriate training programs.

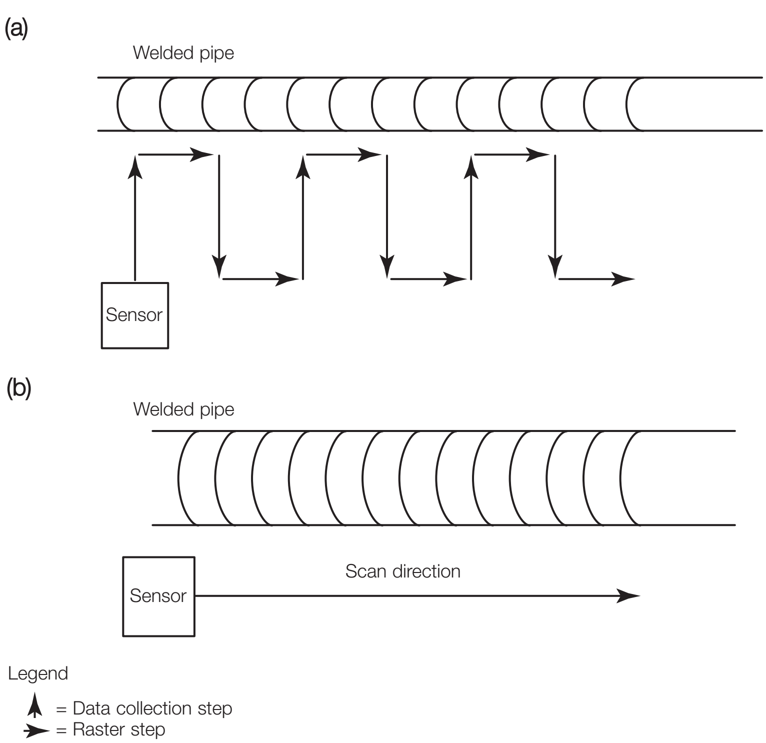

Figure 7. Scanning: (a) conventional raster; (b) linear.

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