Typically, either manual or automated welding is used to join the sections of pipe together that form a pipeline. Since pipelines operate at a high percentage of yield strength, these welds must be constructed and inspected to a high standard. In recent years, engineering critical assessment (ECA), which can also be called fracture mechanics, fitness for service, or structural integrity, has been used to evaluate defects because ECA is considerably less conservative than traditional “workmanship” criteria. Engineering critical assessment is advantageous as it can significantly reduce reject rates (Ref. 1).

Compared with radiography, automated ultrasonic testing (AUT) offers the advantage of process control, as welds can be inspected soon after completion, and feedback given rapidly to the welding crew. Overall, AUT can save construction costs by process control and the use of ECA to minimize the reject rate, often below 1% (Ref. 2).

Ultrasonic phased arrays present major improvements over conventional multiprobe ultrasonics for inspecting pipeline girth welds, both for onshore and offshore use. Probe pans are lighter and smaller, permitting less cutback; scans are quicker due to the smaller probe pan; phased arrays are considerably more flexible for changes in pipe dimensions or weld profiles and for different scan patterns. More important, some of the potential advantages of phased arrays are now becoming commercially available. These applications include the following:

- Compensating for variations in seamless pipe wall thickness.
- Premium inspections for risers, tendons, and other components.
- Small-diameter pipes.
- Clad pipe.
- Special weld profiles.
- Double jointing.
- Seam weld inspections.
- Portable phased arrays for tie-ins and repairs.
- Software modifications.

**Ultrasonic Phased Arrays for Pipeline Girth Welds**

Phased arrays use an array of elements, all individually wired, pulsed, and time-shifted. These elements are typically pulsed in groups of ~16 elements at a time for pipeline welds. In order to make an easy-to-use system, a typical setup calculates the time delays from operator input, or uses a predefined file calculated for the inspection angle, focal distance, scan pattern, etc. — Fig. 1. The time-delay values are backcalculated using time of flight from the focal spot, and the scan assembled from individual “focal laws.” Time-delay circuits must be accurate to around 2 nanoseconds to provide the accuracy required. Due to the limited market, complexity, software requirements, and manufacturing problems, industrial uses have been limited until the last few years (Ref. 3).

From a practical viewpoint, ultrasonic phased arrays are merely a method of generating and receiving ultrasound. Consequently, many of the details of ultrasonic inspection remain unchanged; for example, if 7.5 MHz is the optimum inspection frequency with conventional ultrasonics, then phased...
arrays would typically use the same frequency, focal length, and incident angle.

While 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 transducers.

Using electronic pulsing and receiving provides significant opportunities for a variety of scan patterns.

**Electronic Scans**

Multiplexing along an array produces electronic scans — Fig. 2. Typical arrays have up to 128 elements, pulsed in groups of 8 to 16. 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. Linear scans are straightforward to program. For example, a phased array can be readily programmed to inspect a weld using both 45- and 60-deg shear waves, which mimic conventional manual inspections or automated raster scans.

**Sectorial (Azimuthal) Scans**

Sectorial scans use a fixed set of elements but alter the time delays to sweep the beam through a series of angles — Fig. 3. 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 (Ref. 4), to map out the features (and defects). Depending primarily on the array frequency and element spacing, the sweep angles can vary from ± 20 deg up to ± 80 deg.

**Combined Scans**

Phased arrays permit combining electronic scanning, sectorial scanning, and precision focusing to give a practical combination of displays. Optimum angles can be selected for welds and other components, while electronic scanning permits fast and functional inspections. For zone discrimination scans of pipeline welds, specific angles are used for given weld geometries, as shown in Fig. 4.

**Pipeline AUT Inspections**

Pipeline AUT uses fully automated equipment traveling around the pipe on a welding band in a linear scan, with the array pulsing to cover all the weld zones as in Fig. 4. Besides linear scanning, there are four specific features of pipeline AUT:

- Zone discrimination
- Special calibration blocks
- Dual gate output display
- Rapid defect sizing.

These features are described in detail elsewhere (Ref. 1). The special output display uses multiple strip charts, with color-coded detection; the dual gate display shows both signal amplitude and time in the gate for defect location in the weld; the calibration blocks use an angled notch or side-drilled hole to represent incomplete fusion, one reflector for each zone. Rapid defect sizing is performed by counting the number of zones where above-threshold signals occur. These features are defined by ASTM E-1961-98 (Ref. 5). R/D Tech has a commercial phased array system, PipeWIZARD (Ref. 6) that can also meet or exceed any of the other codes [API 1104, DNV OS101, and ISO 13847 (Refs. 7–9)].

**Advanced Inspections**

One significant feature of phased arrays is their ability to perform “specials.” Some examples follow.
Compensating for Variations in Seamless Pipe Wall Thickness

Offshore seamless pipe has significant variations in pipe wall, up to 10–15%. For a 20-mm wall, these variations are sufficient for the zone discrimination beams to completely miss their targets. One phased array solution is to run multiple setups, typically the nominal, minimum, and maximum walls (Fig. 5); the minimum and maximum setups can be performed electronically, based on a nominal calibration. The operator selects which “view” to watch based on wall thickness measurements (Ref. 10).

Premium Inspections for Risers, Tendons, and Other Components

Risers and tendons are nominally built to much higher quality than standard pipelines or other welds. For example, acceptable defect sizes on 35-mm walls may be only 0.3 mm, with a sizing error of ± 0.3 mm. Phased arrays work better on such applications since they can use multiple beams at multiple angles to guarantee better coverage and defect detection.

Figure 6 shows a schematic ray tracing, showing enhanced coverage of the root, cap, and volumetric areas using an increased number of beams and angles. In this application, the phased array system used 84 beams (not all shown), which would have been impractical with a multiprobe system.

Small-Diameter Pipes

Small-diameter pipes are difficult to inspect well using conventional ultrasonics since there is a limit to the number of transducers that can be placed on the pipe. Phased arrays can generate an almost unlimited number of beams to provide coverage at different angles, locations, and rastering. Figure 7 shows a small-diameter pipe scanner that can be added to PipeWIZARD or operated independently. This scanner requires four rings to cover diameters from 60 to 400 mm.

Clad Pipe

Clad pipe is becoming more common for corrosion resistance. Normally cladding is austenitic stainless steel or nickel alloy based. Both materials can be difficult for conventional shear wave ultrasonics — large austenitic grains skew and attenuate shear wave beams. Longitudinal waves (L-waves) are significantly less affected, so standard practice in the nuclear industry (which uses a lot of austenitic piping) is to perform L-wave inspections. L-waves can be easily generated by phased arrays, but the standard zone discrimination approach (Ref. 5) will not work since it is not practical to bounce beams off the inside of the clad pipe. Developments are ongoing in this area. Figure 8 shows an L-wave scan of a pipe, showing notches and notch tips (lower left quadrant).

Special Weld Profiles

A number of applications have special weld profiles and significant geometrical constraints. Often these welds are structurally critical, e.g., for risers. Phased array inspections can be custom tailored to these welds and geometries by using smaller arrays, special scans, or specific array positioning. Figure 9 shows a schematic of a geometrically challenging weld for AUT, inspected using phased arrays.
Double Jointing

Double jointing is used both onshore and offshore to speed pipeline construction. Automated ultrasonic testing in general offers significant production advantages as there is no safety hazard to reduce production speed, and feedback is essentially in real time. Phased arrays offer the further advantages of additional scans and flexibility in different weld profiles or parameter sets. Figure 10 shows a photo of double jointing for the Blue Stream pipeline.

Seam Weld Inspections

For longitudinal seam weld inspections, phased arrays offer their usual advantages: flexibility for different weld profiles, rapid setup file recall, additional inspections. Figure 11 shows a seam weld scanner, built as an adjunct to the system. This scanner was used in China in 2002.

Portable Phased Arrays for Tie-ins and Repairs

While large AUT phased array systems can be used for both tie-ins and repairs, economics and practical considerations favor smaller, portable systems. An encoded array, calibration block, and appropriate setup can perform a rapid linear scan; C-scan and B-scan displays are generated in real time. The OmniScan system (Ref. 11) in Fig. 12 can perform both electronic and S-scans; the resultant scan patterns are closer to ASME-type raster scans than to ASTM E-1961 zone discrimination, but are suitable and acceptable for tie-ins and repairs.

Software Modifications

With the customizing capabilities of phased arrays, suitable software and displays are essential. Figure 13 shows an example of a user-friendly display, showing defect locations on the weld and position/length around the circumference.

Conclusions

1) Ultrasonic phased arrays offer considerable technical advantages over conventional multiprobe AUT systems or radiography.
2) Using phased array AUT, operators can simply load a file to provide rapid scanning.
3) For pipelines, phased arrays offer some specific applications that are difficult or impossible for multiprobe systems to match. These include the following:
   - Compensating for variations in seamless pipe wall thickness.
   - Premium inspections for risers, tendons, and other components.
   - Small-diameter pipes.
   - Clad and austenitic pipe.
   - Special weld profiles.
   - Double jointing.
   - Seam weld inspections.
   - Portable phased arrays for tie-ins and repairs.

References

phased arrays for faster, better and cheaper inspections. NDT.net, Vol. 5, No. 10, www.ndt.net/article/v05n10/lafont2/lafont2.htm


