The Evolution and Benefits of Phased Array Technology for the Every Day Inspector

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Abstract. Phased arrays were transitioned from the medical field to industry in the early 1980's. Initial industrial phased array technology was reserved for highly complex inspections in critical power generation applications. Equipment was extremely bulky and required highly skilled operators. This paper will describe the evolution and implementation of industrial phased array systems that now allow use by a single operator for everyday applications. Factors discussed include miniaturization of electronics, advances in setup protocol, standardization of ultrasonic phased array probes and wider spread acceptance of the technology by governing agencies, such as ASME, AWS and ASNT.

Origins of Phased Array Technology:

Ultrasonic technology has been applied in both medical and industrial fields since the mid-twentieth century. In its simplest form, ultrasound operators evaluate singular A-Scan reflections (waveform displays) to monitor defect or thickness conditions. The need to establish point-to-point relationships in image form was recognized early on as a means to ease and improve interpretation of data. By correlating relative changes that occur point to point in image form, it is easier to represent small changes in the ultrasonic reflection at particular beam positions. Visual reference thus significantly enhances operator data acquisition integrity and proof of result. First generation imaging was based on B- and C-mode imaging using single element transducers and mechanical scanners C-mode imaging provides a planar view by mapping signal amplitude from a gated region to two dimensional positional data in color or grey scale. B-mode imaging provides cross-sectional image by mapping the A-Scan of interest to changes in the linear position of the transducer (***Figure 1***).

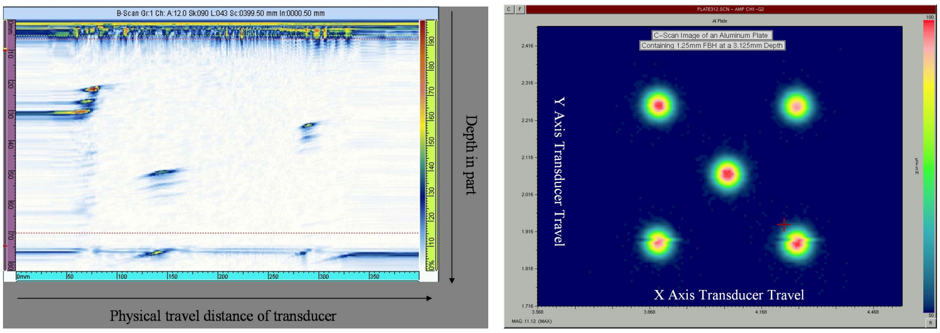

Figure 1 . Examples of B and C Mode Imaging

Obvious disadvantages are the bulky mechanical systems required for imaging, and limitations of single element probes in locating features at various depths and orientations.

In order to reduce dependencies on difficult-to-deploy mechanized scanners, the concept of real time sectorial scans was first introduced in the mid 1960's by Richard Soldner. He developed a mechanical sector-based scanner using transducers rotating in front a parabolic mirror to produce fetal images at 15 frames per second [1].

Electronic phased array scanning across multiple elements was first described by James Sumner in 1968[1]. The concept of phasing pulse and receive signals across multiple point source elements to effectively steer an ultrasonic beam (***Figure 2)***, spurred development.

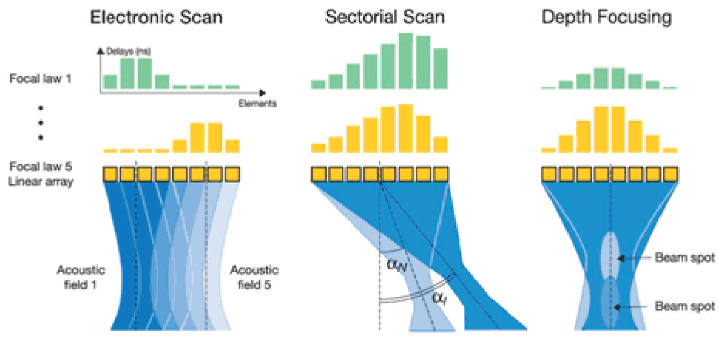

Figure 2. Concept for generation of linear and sectorial scans using phased arrays[2].

This technology, introduced as real time scanners in the early 1970's, offered real time electronic scanning capability with the means to change angle, position and/or focal depth from a single multi-element transducer and thus successfully generate "field of view" images (***Figure 3***).

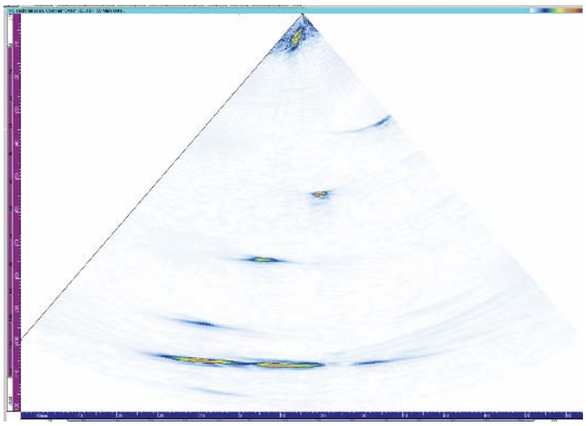

Figure 3. -40 to +40 degree electronic sectorial scan for volumetric metals inspection

The Leap from Medical to Industrial Applications

In many ways the use of ultrasonics in medical clinical diagnostics is aided by the specificity of the medium, human tissue, through which ultrasound travels. Tissue specimens have very similar acoustic impedances (near that of water) and velocities. Modeling is more easily adapted as medium presents fairly consistent background reflections and propagates ultrasound efficiently. Refraction effects are limited as impedance variations are minimal at interfaces and coupling surfaces are smooth and consistent. Low impedance and soft entry surfaces lend themselves well to consistent and efficient ultrasonic coupling. These “constants” were particularly helpful in establishing modeling profiles and diagnostic guidelines which greatly enhanced both interpretation and usability. In addition, regulations for equipment focus mainly on health and safety concerns and diagnostic techniques are not captive to previous codes governing industrial inspection.

Industrial applications, on the other hand, have many additional variables to be considered. The material through which sound propagates is much more diverse. Composite, ceramics, plastics, fiberglass, and of course a variety of metals all vary greatly in acoustic impedance, velocity, grain structure, and surface roughness. Variations in this material not only affect sound propagation within the actual material, but also influence how efficiently one can couple into these samples. The need to generate refracted shear waves in metals for primary construction welding and tubular inspections affects both base operation complexities and transducer standardization. During the process of industrializing phased array instrumentation, the evolution of the transducer also needed to overcome the acoustic and environmental demands of this market sector. The final barrier to adopting mainstream use of phased array technology is adherence to current code requirements or acceptance of new codes that govern nondestructive testing.

First Industrial Systems

The first industrial phased array systems were extremely large (***Figure 4***) [3]. and required data transfer to a computer in order to do the processing and image presentation. These systems typically required at least two operators to deploy. In most applications this equipment required customized phased array probes and was generally used in conjunction with controlled mechanized scanners so as to automate the inspection process. In some cases the ability to incorporate beam steering for inspection of complex geometrical inspections justified the cost of equipment for manual inspection of components.

These systems were most typically used for in-service power generation inspections. In large part, this technology was pushed heavily in the nuclear market, where critical assessment more greatly allows use of cutting edge technology for improving probability of detection. While methods need to be proven to be reliable, in-service inspections are generally less dominated by codes.

Figure 4. Industrial Phased Array system**s** for friction stir weld inspection

Movement toward Portable Solutions

The ability to transition from analog designs that required power and space in creating the many channel and delay configurations necessary for beam steering, into the digital world, enabled more rapid development of the next generation phased array equipment. In addition, the availability of low power electronic components, better power-saving architectures and industry-wide use surface mount board design led to miniaturization of this advanced technology. This, coupled with embedded processors, allowed development of battery operated transportable phased array equipment (***Figure 5***). By providing a phased array tool which allows electronic setup, data processing, display and analysis all within a portable device, the doors were opened to more widespread use across the industrial sector. This in turn drove the ability to specify standard phased array probes for common applications.

Figure 5. Portable Phased array instrument for multi-angle rotor inspection illustration

Benefits for the Everyday Inspector

The benefits of phased array technology over conventional UT applications come from its ability to use multiple elements to steer, focus and scan beams with a single transducer assembly. Beam steering, commonly referred to sectorial scanning, can be used for mapping components at appropriate angles. This can be done to ease inspection of components with complex geometry. The small footprint of the transducer also aids inspection of such components in situations where there is limited access. Sectorial scanning is also typically used for weld inspection **(Figure 6)**. The ability to monitor such specimens with multiple angles greatly increases the probability of detection of anomalies.

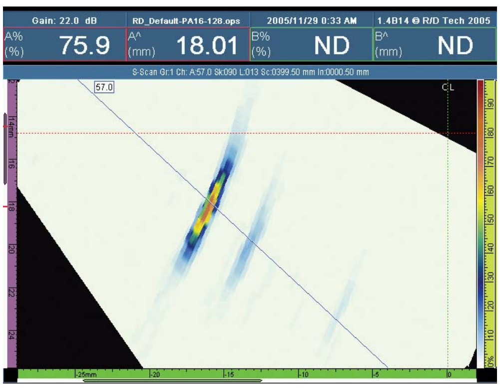

Figure 6. Sectorial image (40 – 75 degrees) of lack of fusion in weld using 5 MHz, 16 element probe

Electronic focusing permits optimizing the beam shape and size at the expected defect location, as well as optimizing probability of detection. The ability to focus at multiple depths also improves the ability for sizing critical defects for volumetric inspections. Focusing improves signal-to-noise ratio significantly, which also permits operating at lower pulser voltages. Electronic scanning across many groups of elements allows for C-Scan images to be produced very rapidly **(Figure 7).** In this case the length of the transducer, consisting of multiple elements, defines the electronic raster axis, and the physical linear movement, often time encoded, provides the scan axis.

Figure 7. Encoded 128 element probe shown with water box for electronic linear C-Mode imaging of composites

With the advent of all-in-one portable phased array equipment, all the benefits of the phased array technology can be realized in a small package. Standardization of ultrasonic probes has targeted specific industrial applications. This makes it easier for typical end users to identify their needs and acquire phased array probes for angle beam, contact and immersion applications. The software and user interface has improved dramatically. Improved user interfaces allow inspection to be readily configured. Typically, the phased array probe is recognized by the hardware, which loads initial setup parameters such as number of elements and frequency that are known. The end user is then guided to program the probe for the type of scan to be done. The equipment automatically calculates the focal laws to generate the intended scan. To ease angle beam focal law calculation, removable wedge parameters are stored in a library and loaded for inclusion in calculations when user selected.

Calibration has also been greatly simplified. In order to have a proper calibration all reference reflectors must give the same reflection anywhere along the sound path. Codes governing weld inspection typically refer to use of DAC curves (distance amplitude correction) to accomplish this for single element probes[4]. This is inherently more complex to accomplish with phased array. For each angle produced, wedge delay must be compensated so depth measurements can be accurately recorded. Angle Corrected Gain (ACG) is also required as amplitude for each angle will vary due to travel path differences. Modern portable systems will thus have a multi-tiered user-assisted automated calibration procedure consisting of velocity calibration, wedge delay calibration and sensitivity calibration. Wedge delay calibration is typically done on a radius or known reflector for angle beam inspection and off the back of a known test block or wedge for zero degree electronic scans (***Figure 8).*** Sensitivity calibrations are performed by sweeping the transducer off a known reflector (***Figure 9***) [5]. After sensitivity calibration is done, a time corrected gain curve than can be built for same size reflectors at various distances to account for volumetric material attenuation effects.

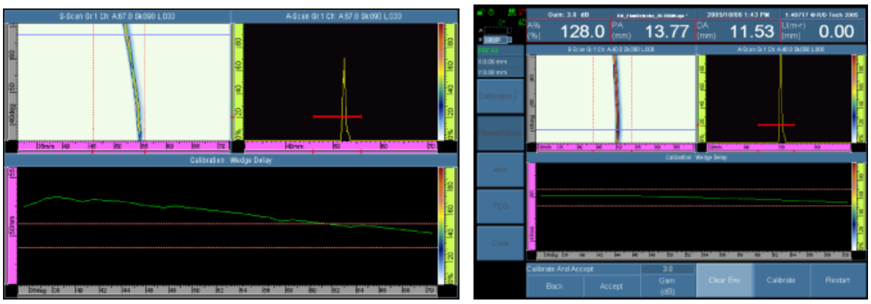

Figure 8. Left: B-Scan, A-Scan and calibration curve for uncompensated wedge delay
Right: B-Scan, A-Scan at end wedge delay calibration procedure.

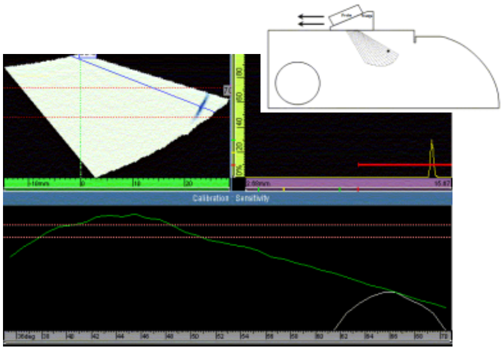

Figure 9. Sectorial scan, A-Scan and sensitivity curve from reflector –uncompensated. Shallower angles brought to 80% upon calibration

While there are currently no codes specifically detailing procedures for calibrating phased array probes, many codes do allow procedures for accepting new technologies and techniques. Development of codes is in process, and in the interim use of these assisted calibration methods has increased user confidence for common inspection.

Conclusions:

Over the past 40 years there has been much development in the area of ultrasonic real time imaging through application phased array technologies. This technology is now making rapid inroads in the industrial sector. The many benefits of this technology are already driving rapid development that will lead to gains in performance, ease of use and industry acceptance.

References

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