Phased Arrays vs. Phased Arrays – Beam Sweeping vs. Encoded Data Collection

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Abstract
This article describes the differences between manual and encoded phased array units. While merely adding an encoder may not seem technically demanding, the software requirements and improved capabilities are significant. Many NDT applications cannot be performed by manual (or "beam sweeping") PA units due to code or technical limitations.

Introduction

Phased arrays are one of the hot technologies in NDT at this time, with good reason. Compared with conventional ultrasonics, phased arrays offer significant advantages:

- ***Speed***; for welds, corrosion and other components, linear (or line scanning) scanning can increase scanning speed (and hence reduce costs) significantly.
- ***Imaging***; S-scans, E-scans and other 2D and 3D imaging can give much better and more interpretable defect assessments.
- ***Flexibility***; phased arrays can perform a wide variety of scans, for a wide variety of defects on many different types of components (1).
- ***Data storage***; full or even partial data storage and display allows better defect interpretation, plus can be used for archive purposes.
- ***Reproducibility***; though not demonstrated yet by third party trials, using the same set-up and procedure with phased arrays gives much more reproducible results than with manual ultrasonics.

However, there is more than one type of phased array instrument available on the market. Besides the large, non-portable units which have been available for a decade, there are portable units available from several manufacturers. The portable units themselves can be divided into two categories: manual and encoded, and the differences and capabilities are significant. This article describes the various features and capabilities, plus mentions some of the different types of applications that can be performed with manual and encoded units.

Phased arrays are quite well referenced in the literature, so this paper will not describe them. For a broad assessment of the physics, hardware, software and sample applications, see (1).

Beam Sweeping PA Units

The beam sweeping units, i.e. the manual units, operate like upscale monocrystal units that can also sweep the beam. These units use a manually-held array in much the same manner as a manual probe, i.e. the array is rastered toward and away from the weld or component, and the operator watches the screen for defects. The main difference is that the operator also sees an S-scan (see Figures 1 and 3 for examples) or E-scan, which can assist in defect analysis.

In general, data is not collected, though screen displays can be saved and reported. In some manual units, it is possible to collect scans using time-based data collection; however, this data is inherently unreliable compared with encoded data since the measured defect length will depend on the operator's scanning speed, and the lengths are not calibrated. Time-based scanning, or beam sweeping, is specifically not acceptable for AUT codes such as ASME Code Case 2235 (2).

Why buy a beam sweeping unit? There are several possible reasons. If the unit can display multiple A-scans at one time (e.g. 45, 60 and 70^{o} for AWS D1:1 inspections – see ref 3), then potentially the operator can scan faster. (Of course, the unit must be calibrated to the meet the ASME or other Code.) As mentioned above, under some circumstances 2D images can improve defect assessment and data storage. For some applications, e.g. Hydrogen Induced Cracking, a beam sweeping unit may be adequate. And the cost is lower.

What beam sweeping units cannot realistically do is store full data, perform multiple functions simultaneously, and perform linear scanning. These are covered below.

Beam sweeping units are available from various manufacturers, and Figure 1 shows a typical manual PA unit.

Figure 1: Commercial beam sweeping (or manual) PA unit: Olympus NDT's OmniScan M (the "manual" PA version). Note that other manufacturers also produce beam sweeping units.

Encoded PA Units

Encoded phased array units have the capability of using an encoder for collecting and storing scan data and probe position data. While this may not sound like a big difference – after all, adding an encoder to an electronic unit is theoretically not a big deal – the real story is in the software. Encoded PA units can collect full A-scan waveform data, store and manipulate displays to give "top, side, end" views and process this data. In other words, encoded PA units are a portable, low cost AUT (Automated Ultrasonic Testing) system, whereas beam sweeping PA units are glorified monocrystal units. Scanned data can be replayed for offline data analysis.

Encoded PA units offer major time and cost advantages for components like welds. Figure 2a shows the traditional raster inspection process, with the probe being moved back and forth towards the weld. Figure 2b, on the other hand, shows weld inspections using "linear scanning", i.e. inspecting using a single pass parallel to the weld while the array performs the rastering. Beam sweeping PA units perform raster scanning (Figure 2a), while encoded PA units can perform linear scanning (Figure 2b) as well.

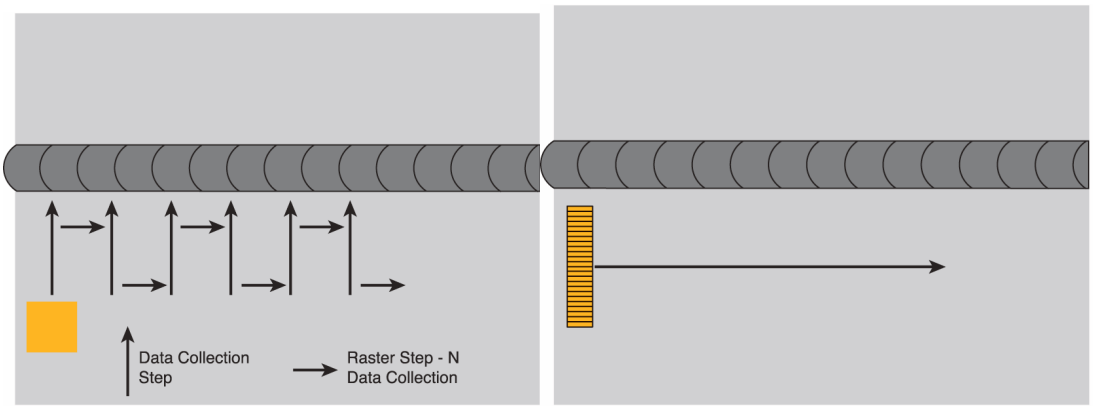

Figure 2a (left), conventional raster scanning. Figure 2b (right) linear scanning.

Linear scanning offers significant advantages in speed, maybe up to a factor of five or ten times over monocrystal inspections. Besides collecting and displaying all the defects, some encoded PA units can perform multiple scans simultaneously, i.e. they can fulfill the code requirements in a single pass, with arrays on either side of the weld (see Figure 3). The more advanced units can also perform additional scans like TOFD.

Figure 3: Multigroup screen display from OmniScan MX for encoded scanning. Note that other manufacturers also produce encoded portable phased array units.

Naturally, with encoder capability, data storage, display reconstruction, more channels and some signal processing, the encoded PA units are more expensive than the beam sweeping PA units. They also require more training. However, for the correct applications, encoded data collection is a much better, more cost-effective solution, and in many cases is the only PA solution (see Sample Applications below). Figure 3 shows an example of an encoded PA unit.

PA Code Compatibility

Though phased arrays are new, there is a big push from the marketplace to get phased arrays accepted by the various codes. Fortunately, most of the major US codes like ASME (4) and AWS (3) inherently accept phased arrays as a technology, but require demonstration that the proposed technique and procedure fulfill the code. This can be performed through various routes, e.g. ASME Section V Article 14 (5), or through ASME Code Case 2235 (2). It is important to check if encoded data is required, as with ASME CC 2235.

At this time, ASME is arguably the leader in codifying phased arrays. Code Case 2541 is already in print (6), and other code cases are in progress. One notable feature for phased arrays are the upcoming calibration requirements. ASME has interpreted an S-scan or an E-scan as multiple waveforms, each of which must be calibrated to Code. The new ASTM standard practice for setting up phased arrays (7) has taken the same approach: full Angle Corrected Gain (ACG) and Time Corrected Gain (TCG) are required.

Sample Applications

Beam sweeping PA units are good for applications which require manual manipulation and imaging, typically some in-service applications. Here, crack sizing or defect

characterization is required, as with stress corrosion cracking or Hydrogen Induced Cracking. Obviously, good data analysis capability and some image storage are beneficial, but most beam sweeping units can fulfill these minimal requirements. Other applications, like bolts, can be performed by beam sweeping units, but these are best performed using mechanized and encoded scanning. Welds can be inspected using beam sweeping, provided the unit can be correctly calibrated, but will not be as fast as encoded scanning, nor will the data be stored. Aerospace applications will depend on the specifics.

Encoded PA units will be beneficial for any inspection that requires reproducible, stored data. This includes code-type weld inspections, manufacturing, corrosion mapping, high speed inspections, remote applications, and precision inspections (1); essentially any application that is currently filled by AUT.

Beam Sweeping or Encoded PA Units?

The answer depends on the applications. For some limited applications, a beam sweeping unit may be adequate, but the purchaser should make sure that the unit can fulfill any codes. For more advanced applications, and greater flexibility, an encoded PA unit is obviously the choice.

One viable solution is to buy an upgradeable unit, so that the operators can move up from beam sweeping to encoded scanning when the applications demand, or when the neophyte operators can move up a development level.

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