PHASED ARRAYS FOR GENERAL WELD INSPECTIONS

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ABSTRACT

Ultrasonic phased arrays have proven to be a very appropriate inspection technique for weld inspections, especially encoded arrays with linear scanning. The flexibility of phased arrays allows them to be tailored to almost any weld profile and predicted defects. Besides showing the normal advantages of phased arrays for welds (high speed, reduced costs, full data storage, increased productivity), the paper will illustrate sample weld inspection Scan Plans and coverage. In addition, some codes have been adapted to the use of phased arrays, so these inspection techniques are effectively controlled and approved. TOFD (Time-Of-Flight Diffraction) can be added for improved detection capability and better sizing. Back diffraction also offers significant benefits for accurate sizing.

INTRODUCTION

The concept of phased arrays has been around for decades, but only in the last sixteen years can industrial phased arrays (PA) be called “commercial”. The principles of phased arrays are well documented (1, 2) elsewhere. Phased arrays have significant advantages over conventional inspection techniques: flexibility, high speed, lower costs (under many conditions), full data storage for auditing, and significantly increased productivity (for volume inspections).

Phased arrays can be used in both manual and encoded fashion, which are two completely different approaches (3). This paper deals with encoded scanning, where the true advantages of phased arrays lie. Manual phased arrays are more similar to conventional ultrasonics. Figure 1 (left) shows a typical instrument. On the right is a screen shot showing multiple groups performing simultaneous scanning with encoders; this helps significantly in fulfilling the various codes. For construction welds, codes are of major importance.

Figure 1: Left, Photo of typical portable phased array instrument. Right, screen shot of multigroup scanning.

In recent years, various codes have been written specifically for phased arrays for weld inspections. These codes have specific requirements for coverage, and for appropriate angles. Typically, the inspection is prepared using a Scan Plan, which shows coverage – or lack of it. Also, the codes cover aspects such as scanning speed, beam coverage, calibration etc. In many cases, the addition of Time-Of-Flight Diffraction (TOFD) has major advantages, and tends to cover where phased arrays are weaker (midwall defects and accurate vertical sizing).

LINEAR SCANNING

One of the big changes in Automated Ultrasonic Testing (AUT) was the switch from raster scanning (which is very time-consuming) to linear scanning, as shown in Figure 2.

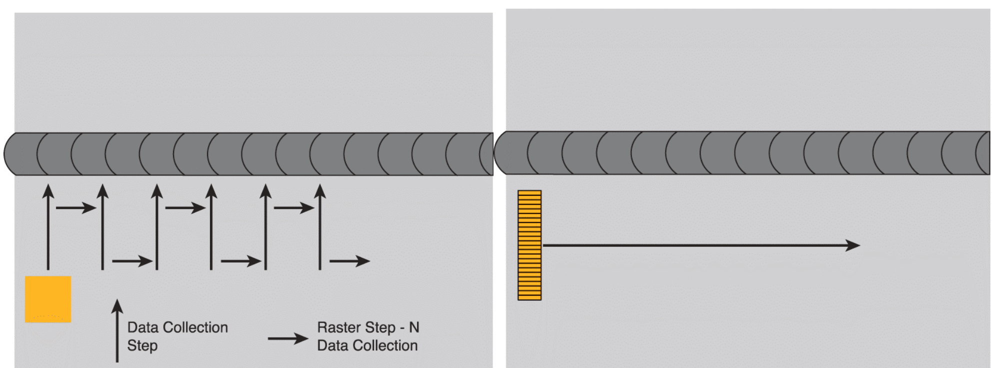

Figure 2: Left, raster scanning. Right, linear scanning along weld.

This change required moving from conventional single-channel ultrasonics to either multi-probes, or more recently to phased arrays. The time savings were impressive, often an order of magnitude.

CODE REQUIREMENTS

The dominant code for weld inspection, both globally and for phased arrays, is ASME, specifically Section V (4). ASME has published five separate Code Cases (5) on phased arrays to cover both manual and encoded scanning, and is working on a PA Mandatory Appendix. These Code Cases specify many of the parameters and requirements for performing phased array inspections, specifically:

- All beams must be calibrated, whether S-scan or E-scans
- "Essential Variables" must be listed, as normal in ASME
- Additional phased array parameters must be documented
- A "Scan Plan" is required (see below)
- Full data collection is required, as per ASME Code Case 2235 for AUT (6)
- 6 dB beam overlap is required for coverage, which refers to both S-scans and E-scans
- Limited data drop-out is allowed.

There are other conditions, but these are the dominant ones.

Other organizations, e.g. the American Petroleum Institute, also approve phased arrays, and follow a similar philosophy. While these rules are general and require some thought on the part of the Level III, they are functional in most cases.

Some of the specific advantages of phased arrays will now be illustrated: flexibility, speed, productivity, data storage.

FLEXIBILITY

As phased arrays use electronic control of the beam, the angles, wave modes, scan patterns and coverage are all controlled by the set-up. Figure 3 shows a typical Scan Plan for a thin-walled weld. Note that a single beam is adequate for thinner walls, but not for thicker walls; this would be determined from the Scan Plan. Figure 4 shows an inspection of a thicker-wall T-weld using two S-scans.

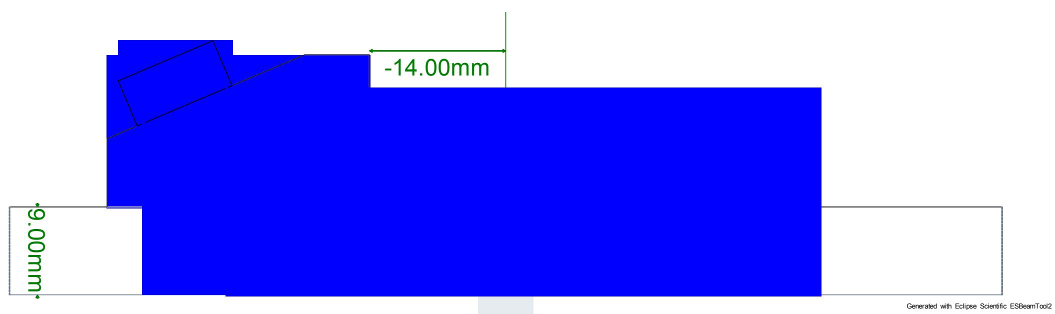

Figure 3: 9mm Wall using standard 45-70° refracted shear wave S-scan.

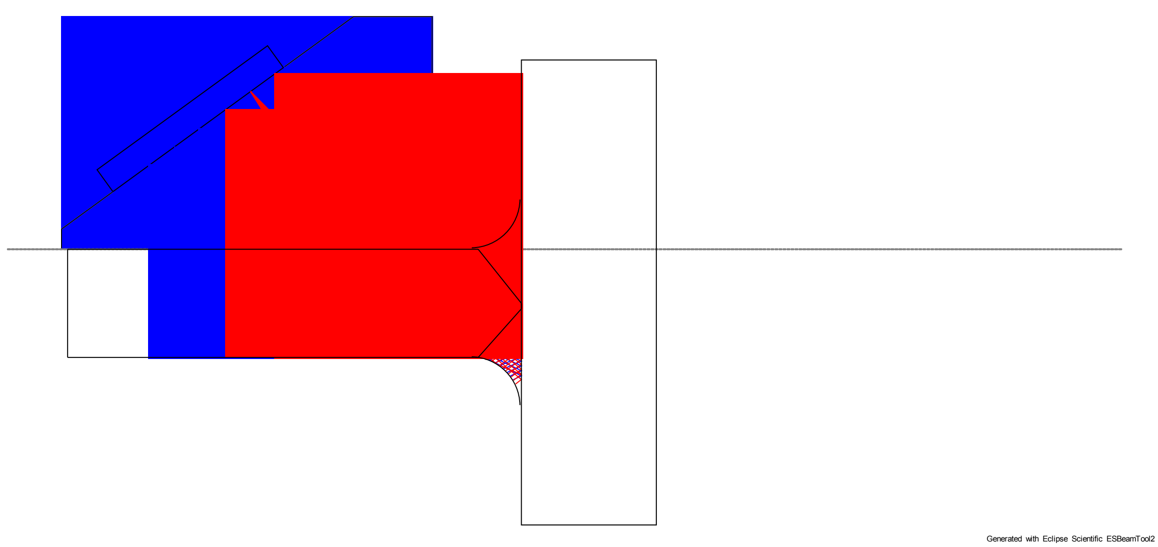

Figure 4: 20mm beveled T-weld using standard 45-70° refracted shear wave S-scans with two standoffs

INSPECTION SPEED AND IMPROVED PRODUCTIVITY

While cost data and productivity are normally proprietary information, such data that is available shows that much improved scanning speeds are obtainable. Table 1 compares scan times and productivity from manual UT to radiography to PA (7). Not surprisingly, the latest technology (PA) comes out well in front.

Based on a 2" Butt Weld .200" MWT & 100% access to circumference								
Method	**Crew Size**	**Scan / shot time**	**Set-up time**	**Welds per hour**	**Production Interruption**	**Safety Hazards**	**Report format**	**Auditable Results**
RT	2 man	5 min.	5 minutes per/weld	**6 to 10**	**100%**	**100%**	Image of weld	**YES**
Manual UT	1 man	10 min.	5 minute per/weld	**4 to 6**	**0%**	**0%**	Hand Written	**NO**
Mech. PA	2 man	30 sec	3 minute per/weld	**10 to 20**	**0%**	**0%**	Image of Weld	**YES**

ASSUMPTIONS

1. Amounts are based on averages, results will vary.
2. RT: Assumes 2 exposures with 50 curie source.
3. Manual UT: Assumes minimum scanning requirements as per ASME.
4. Set up time is based on typical accessibility and work plan.

NOTE: Does not include time and or cost for film processing, reporting, re-shots, etc.

Table 1: Comparisons of small pipe weld inspections times and conditions for manual UT, RT and phased arrays.

Similar results have been obtained elsewhere. The net effect, particularly in high wage countries, is that equipment costs are a relatively small fraction of the overall price, but scanning speed is so much higher that PA are definitely cost effective. These benefits occur most clearly when the inspection is on a well-defined geometry and is relatively high volume.

FULL DATA STORAGE

In some industries, e.g. Oil & Gas, auditing the results is a key issue. Encoded scanning permits full data storage, as defined by code. In addition, the data can be reprocessed afterwards, e.g. for more detailed analysis or for alternative evaluation thresholds. In normal weld inspections, PA collect multiple data channels simultaneously at high speed, so the operator cannot analyze all the data at once. Thus, the best choice is to select suitable channels for monitoring to ensure the scan is progressing OK – and also to get preliminary feedback for subsequent analysis. Typically, the TOFD channel works well for monitoring (see below).

After scanning, the data can be reprocessed as "top, side, end" views or whatever the contractor or contract specifies. Figure 5 shows an example.

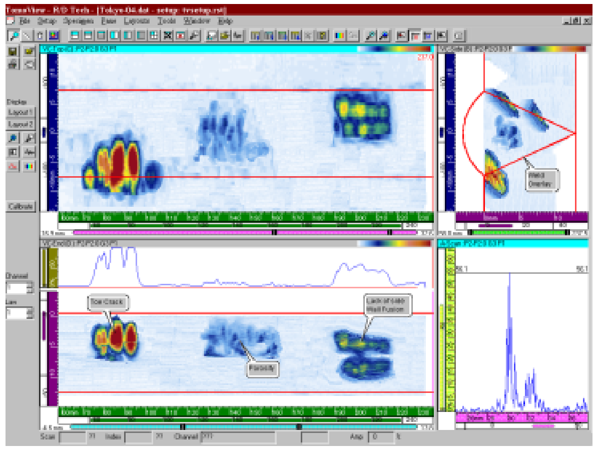

Figure 5: "Top, side, end" view of weld showing defects.

SCAN PLANS FOR COVERAGE

One of the more important aspects of encoded linear scanning is to ensure that correct coverage of the weld is obtained, including any scanning errors. Conveniently, the arrival of lower cost ray tracing software specifically for weld inspections (e.g. ESBeamTool (8) and Scan Plan (9)) has made the set-up operator's life much easier. Figure 6 shows an example of a weld set-up that shows inadequate coverage (10). Compare Figure 6 with Figures 3 and 4 for coverage.

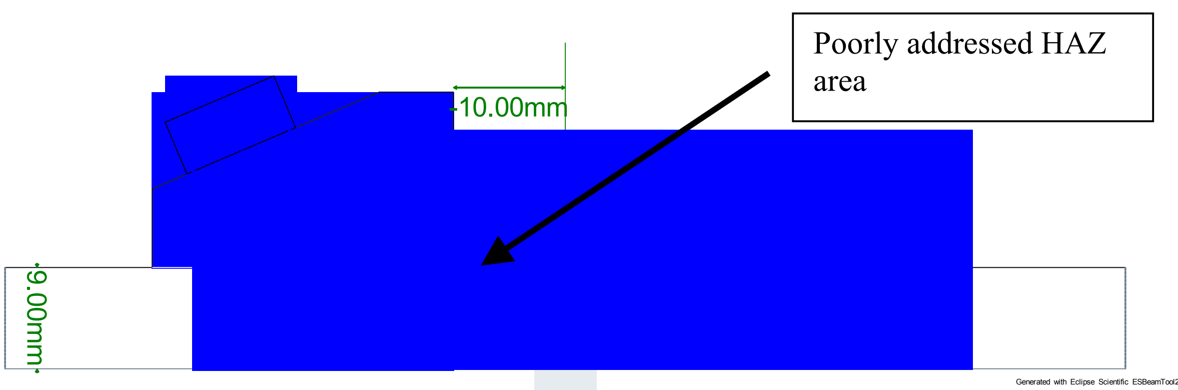

Figure 6: Scan Plan from ESBeamTool showing poorly addressed HAZ

In addition, bevel incidence angles should be as close to normal as possible. ASME does not specify what these angles should be, but the generally accepted maximum is $\pm$ 10^{o} – if possible. Figure 7 shows an example of a Scan Plan showing a bevel incidence angle which is perhaps a bit high.

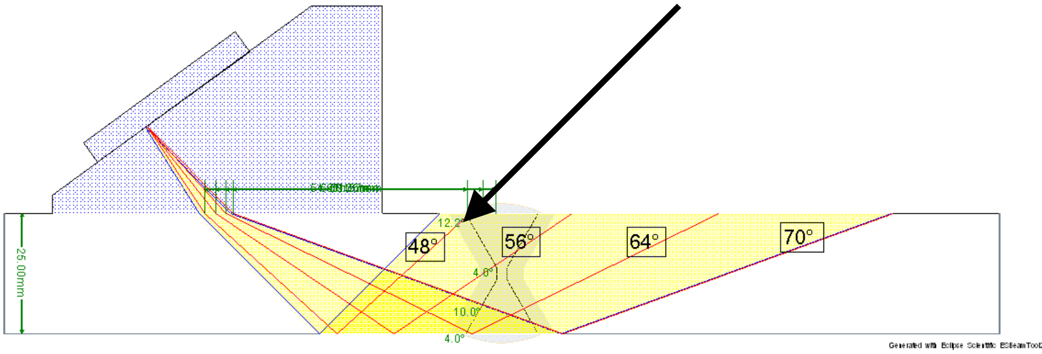

Figure 7: Scan Plan showing high bevel incidence angle in cap area.

TIME-OF-FLIGHT DIFFRACTION (TOFD)

Diffraction is a general phenomenon in ultrasonics, as normal in wave physics (11). The tips of internal defects will diffract an ultrasound beam; this diffracted beam can then be detected and the arrival time accurately measured. The "standard" TOFD set-up is shown in Figure 8.

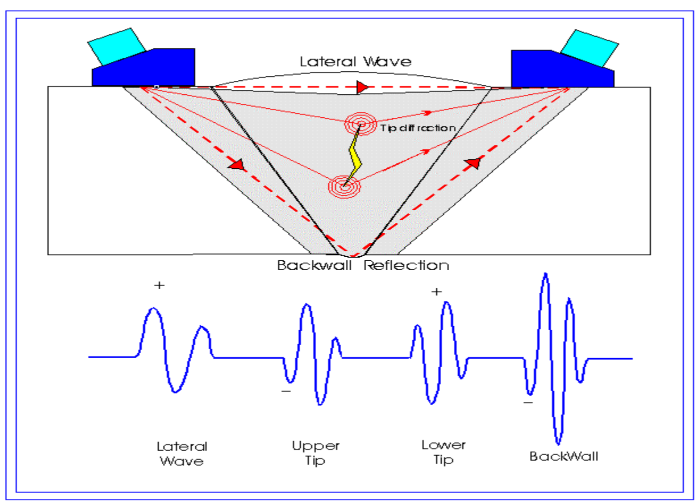

Figure 8: Standard TOFD set-up.

TOFD normally uses a pitch-catch arrangement with the probes symmetrically spaced across the weld. The wedges are angled to generate wide-angle, longitudinal waves (or L-waves), since these arrive first and don't confuse the interpretation. Four types of signals are detected: the Lateral wave; the Backwall reflection; the Reflected wave, and any Tip Diffracted waves from defects. The lateral, backwall and tip-diffracted waves are visible in Figure 8.

TOFD images look like vertical through-sections of the weld. The lateral wave is essentially the OD; the backwall is essentially the ID; and any defects show as tip diffracted signals between these two. Figure 9 shows a typical example of a TOFD scan.

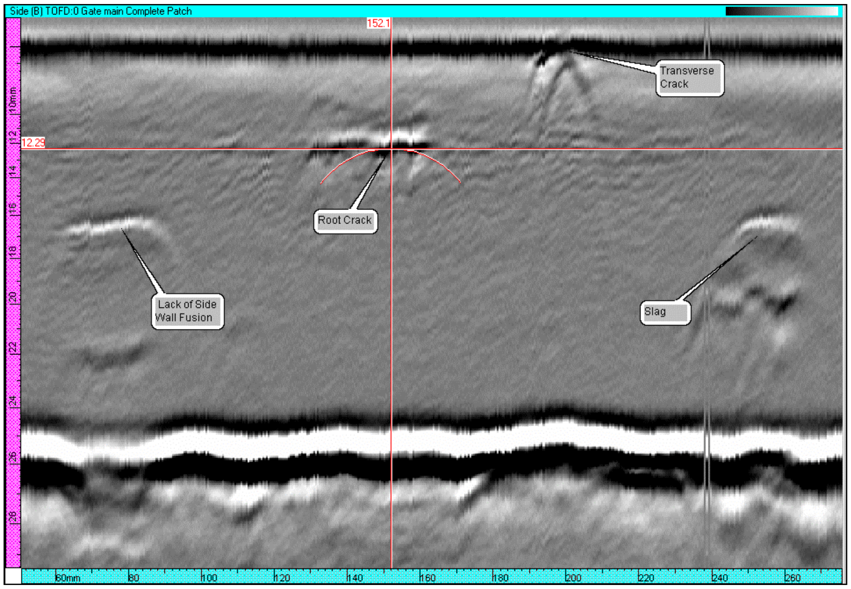

Figure 9: Typical TOFD image showing lateral wave (OD), backwall (ID) and four labelled defects.

TOFD images always use gray scale presentations and full RF waveforms to capture the phase information. As such, TOFD does not require a lot of data collection, and is very fast. As shown in Figure 8, signals are identifiable by their phase. The OD and ID have a phase reversal, as do the top and bottom of defects.

TOFD is a very powerful technique, and allows good midwall defect detection, accurate sizing of defects using the times of arrival of diffracted signals, defect detection even if defects are mis-oriented or located away from the weld centerline, and rapid linear scanning. In addition, set-up is independent of weld configuration. The limitations of TOFD are mainly the dead zones at the OD and ID, plus the interpretation. Overall, TOFD and phased arrays are extremely complementary, and can be run simultaneously.

MECHANICS

In general, PA, AUT and TOFD codes accept any scanner that fulfills their requirements. The two basic types are fully automated and semi-automated. Both use holders to keep the arrays at a fixed distance and orientation to the weld; both use encoders to ensure full data collection. Figure 10 shows a typical automated scanner on a pipe weld, and Figure 11 a similar semi-automated scanner, or handscanner.

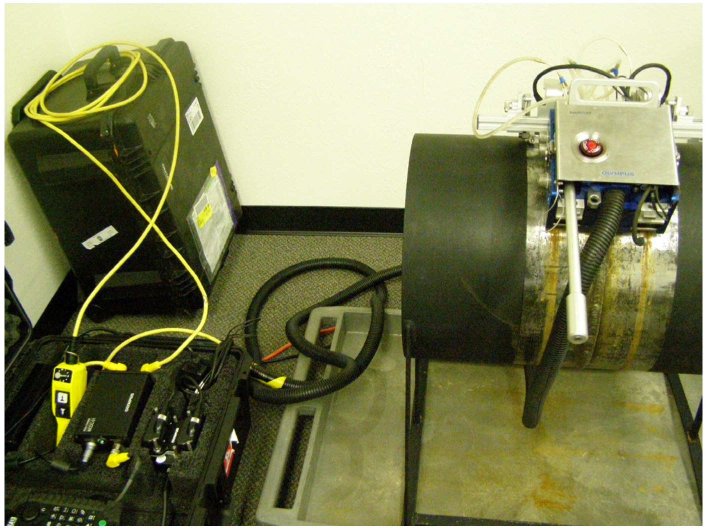

Figure 10: WeldROVER automated scanner on lab pipe.

Figure 11: Encoded PA handscanner with OmniScan MX

SUMMARY

Phased arrays have developed well in the last several years, particularly for weld inspections. Codes have been, or are being, developed – particularly through ASME. Mechanics, set-ups and procedures are available. A number of other developments, e.g. ray tracing for Scan Plans, have come on the market. Essentially, the technology is "ready to go". However, the biggest single limitation still applies – a shortage of trained operators.

CONCLUSIONS

1. Phased arrays, particularly portable phased arrays, have come a long way in just a few years, especially for weld inspections.
2. Specifically, weld inspection codes have been developed, particularly by ASME.
3. Other developments, such as ray tracing and weld overlays have been developed to aid inspection and interpretation.

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