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Phased Array technology for standard ultrasonic testing

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1. Introduction

Years of experience in medical ultrasonic diagnostics and the development of efficient, portable computers now mean that Phased Array technology can be used for standard applications in ultrasonic materials testing. This technology will in the long term revolutionise the test technology previously used because it enables test results to be visualised true to scale and in real time. The A-scan trusted by every ultrasonic tester for over 50 years will lose its importance and be replaced by sector and sectional scans.

2. Phased Array technology

The basis of Phased Array technology forms a probe with a large number of transducer elements which can be arranged either linearly or 2-dimensionally, and can be activated individually, Figure 1. Moreover, a multi-channel ultrasonic instrument is required, which at best is provided with its own pulser and amplifier for each transducer element. Thirdly, programmable electronics ensure that the individual transducer elements can be phase activated. Therefore it is now possible to control the sound field of a phased array.

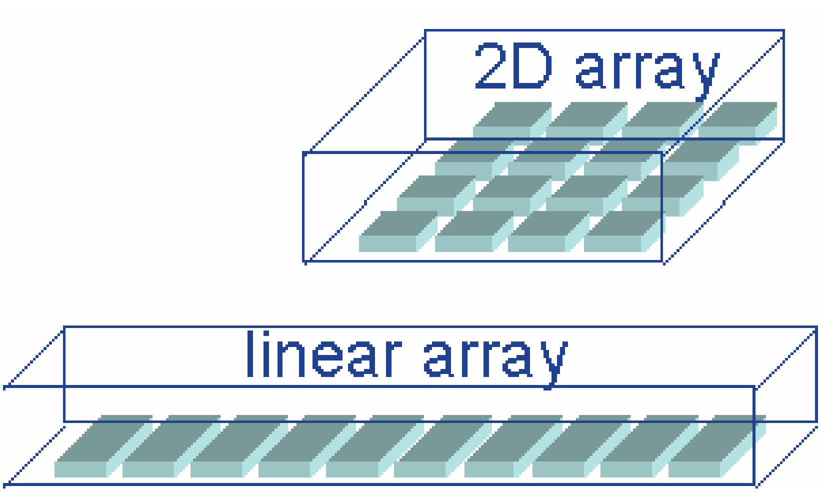

Figure 1: Phased-Array

3. Sound field control

3.1 Linear scanning

The individual transducer elements are activated from one side to the other with constant phasing. Without moving the probe the workpiece is therefore scanned in the plane of the linearly arranged elements, Figure 2.

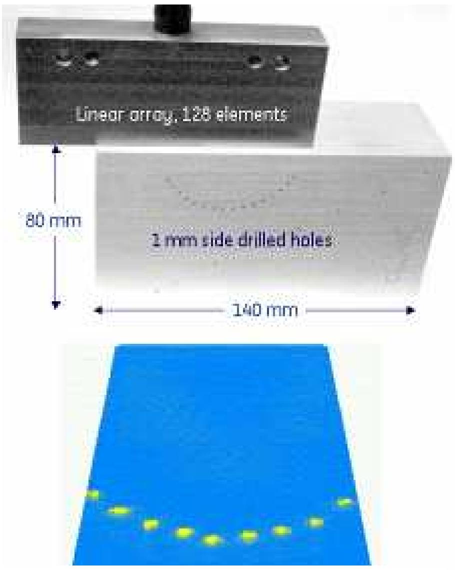

Figure 2: Linear scan

3.2 Steering

Because of the timed activation of the transducer elements a wave front is also generated obliquely to the surface, Figure 3. The steering range of the sound field thus generated may be regulated by suitable control of the phasing, but is limited by a decrease in the acoustic pressure as the angle increases, and by interfering grating lobes.

Due to the additional use of a wedge delay, transversal waves are reverberated in the preferential direction predetermined by the wedge angle. The sound field can also be steered in the range of 35 to 75°, which is typical for the weld inspection.

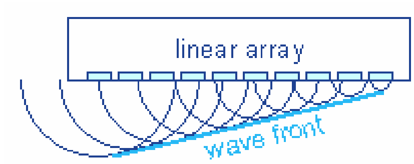

Figure 3: Steering sound field

3.3 Focussing

The sound field of a phased array can be focussed in two ways. If all the transducer elements are activated in parallel, a sound field is created which is identical to that of a single element probe with the same transducer size. This results in the maximum near field length N. If the number of the transducer elements connected in parallel is now reduced, a reduced near field length N' is automatically obtained from the size of the aperture. The second possibility involves phased activation of the transducer elements from outside to inside, thus creating a forced, concave wave front with a preferred focus: the near field length is reduced in a similar manner to the effect of a lens.

3.4 Combinations

Scanning, steering and focussing can be combined almost arbitrarily. Thus a maximum of flexibility in terms of sound field control can be achieved, rendering the use of several probes to perform a test operation unnecessary in practice. Ultrasonic testing becomes faster and hence more economical.

4. Reconstruction

A decisive factor in correctly evaluating the signal of a phased array is the reconstruction of the signals on the receiving side. If the transducer elements are activated in a certain time pattern, a predetermined sound field is obtained, and any reflectors in this range supply echoes which are now received “unsorted” from all transducer elements of the probe. A time pattern must now also be used on the receiver side to ensure that the signals received from the transducer elements are synchronised with the pulser timing. Only now can the associated reflector layers required for a graphic representation be determined for the echoes.

The time pattern which has been calculated for a certain sound field control is also designated in phased array technology as the “delay laws”. The individual transducer elements are activated with the constant pulse repetition frequency predetermined by the system (PRF between 10 and 20 kHz). For a certain desired sound field control a finite number n of pulsing-receiving cycles is now obtained with the time pattern calculated by the delay laws. Within this cycle of n transmitted and received sound pulses the desired range of the workpiece is tested and the graphic representation of the test results calculated at the end of the cycle. This results in the much narrower cycle frequency of PRF/n Hz. In Figure 5 the angle is steered in 16 steps, one for every 4 focus depths: One cycle = 64 shots. At PRF = 10 kHz a cycle frequency of 156 Hz is therefore produced – fast enough for manual ultrasonic testing.

5. Result representations

5.1 A-scan

The A-scan continues to be used in phased array, but it has a different significance here. In the standard application a so-called “total A-scan“ is represented which shows the maximum echo amplitudes of an entire cycle. It is also possible to represent the A-scan for a specifically selected, individual shot k of the cycle, e.g. that for an angle of incidence of exactly 45° or that for a predetermined focal depth of the sound field.
The individual A-scans are generally stored in the device memory within a certain time during recording. All the A-scans may then be considered individually “off line” in an evaluation mode after the actual test.

5.2 B-scan

The B-scan or sectional scan in the plane of incidence of a linear scan is represented immediately after each cycle. All echoes in the scanning range are represented true to scale with their amplitudes in a predetermined colour scale. If the probe is also moved transversely to the scanning direction across the test object, thereby recording the probe position, the test results are stored "in slices" and at the end there are test results of a certain volume from which even a 3D representation of the workpiece can be generated, if necessary.
Since the coordinates of flaw echoes are available in 3-dimensional form when scanning with an encoder, a 3rd view of the test results is also possible: the projection onto the workpiece surface perpendicular to both scanning directions. However, this representation of the test results is not described as a B-scan in most cases, even though it also represents a side view of the tested volume. This representation is sometimes also described as an "end view". When related to the weld inspection this representation enables the flaw length to be determined in the seam direction, Figure 4.

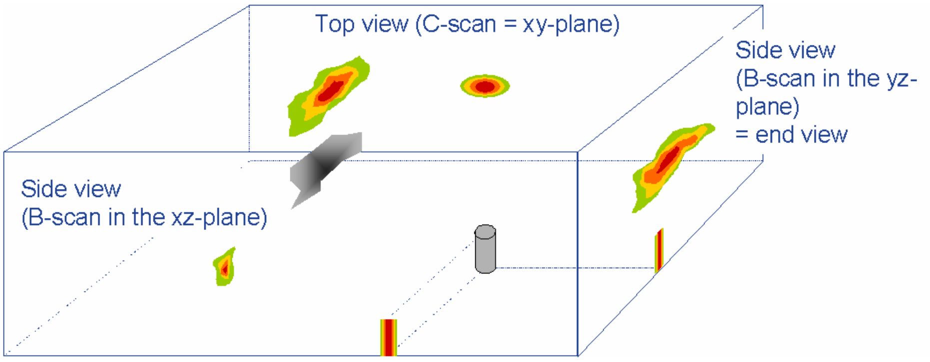

Figure 4: Representation of the result

5.3 S-scan

The sector scan or S-scan is also a B-scan, but one which only represents the steering range of the probe scanned true to scale over one cycle, Figure 5. This is the representation that is normal in medical diagnostics. In the weld inspection all the reflectors are represented in the steering range of the sound field. If necessary, the scanned representation must be suitably adapted for reflecting the sound field on the bottom of the plate -> reflection of the sector = volume-corrected sector representation.

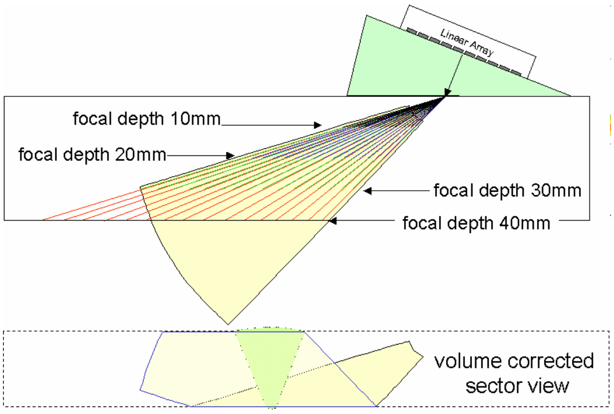

Figure 5: Sector representation with angle probe

5.4 C-scan

The C-scan is a top view of the workpiece. The echoes stored in the volume range represented are projected onto surface. Here two variations are possible: Either the echo amplitudes or the sound paths (D-scan, depth scan), are represented, each coded with a colour or grey scale, Figure 4.

6. Portable Phased Array Instrument

A Phased Array instrument differs considerably from a conventional ultrasonic testing instrument with A-scan representation. After many years of successful application of the phased array technology in automatic testing systems from GE Inspection Technologies (formerly Krautkrämer), there will be a portable Phased Array instrument which is universally applicable but is of particular interest in weld inspection because of its dimensions, Figure 6.

Figure 6: PHASOR 1

7. Application

Side drilled holes in a test piece can be scanned with a 5 MHz linear array. Only 32 of the 128 elements are used for scanning, so that the drilled holes arranged in a semi-circle are recorded in 2 scans. Figure 7 shows the near zone resolution of the linear array, recorded on a stepped element as 3 mm, 4 mm and 5 mm. To demonstrate a weld inspection side drilled holes are first scanned in a test piece 30 mm thick, Figure 8.
A genuine weld seam is then tested, Figure 9. For this purpose the probe is guided at a constant distance along the seam and the probe position is recorded. The C-scan and the B-scan may therefore also be represented in the longitudinal direction, Figure 10. The C-scan is shown at the top left of the diagram. The B-scan is shown on the right in the longitudinal direction, and below it (very narrow) the so-called cycle view for the cursor position in the C-scan. It shows the maximum amplitudes for the entire cycle (here 288 strokes). With the cursor each stroke may be selected so that the associated A-scan and sector scan is shown for this shot, here the shot which the maximum flaw echo shows. The volume-corrected sector scan is shown bottom left, and the corresponding A-scan bottom right. Figure 11 shows the same flaw in an enlarged representation.

Figure 7: Near resolution

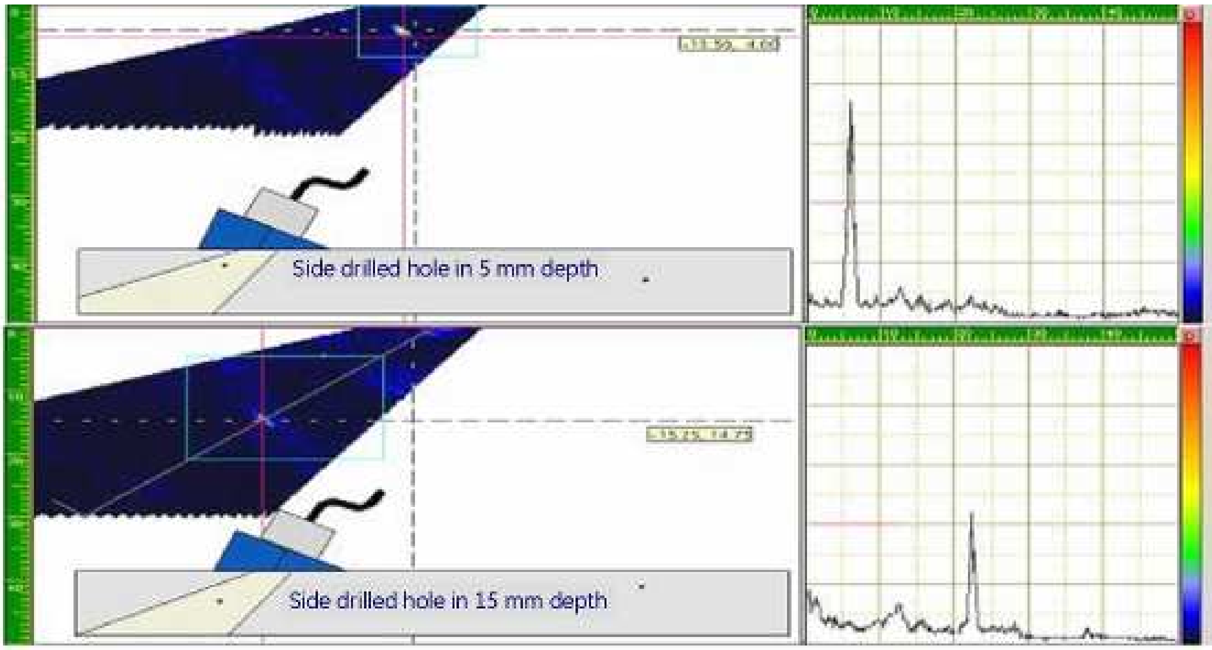

Figure 8a: Side drilled holes at a depth of 5 mm and 15mm

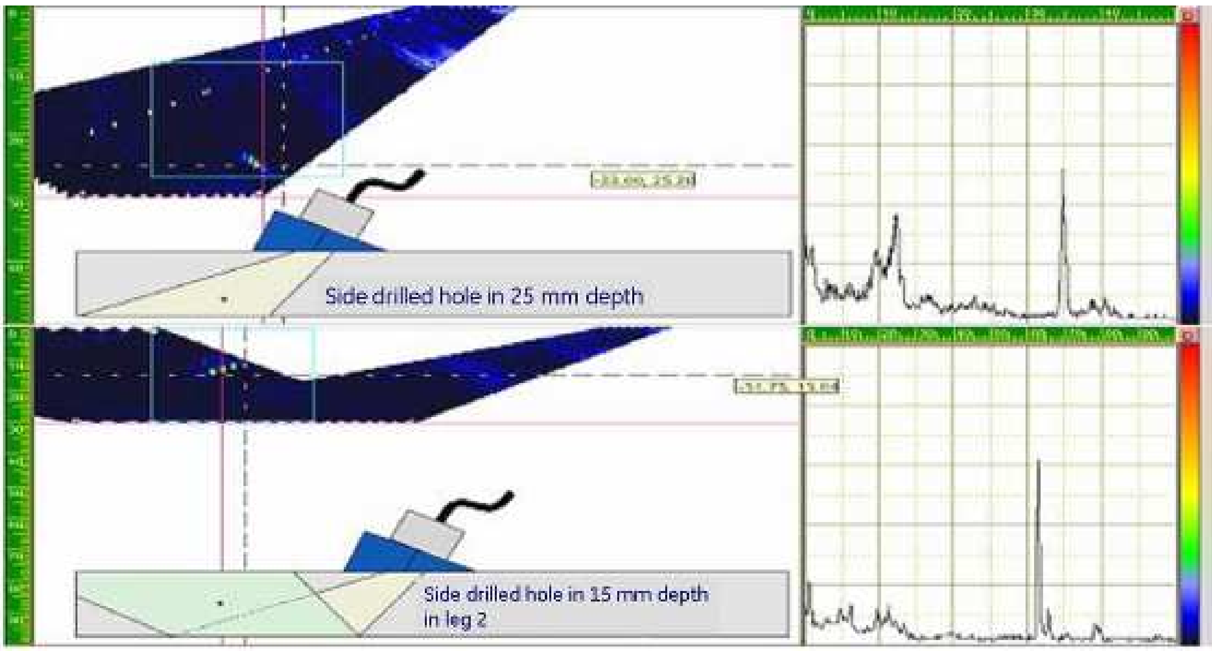

Figure 8b: Side drilled holes at depths of 5mm & 15mm (in reflection)

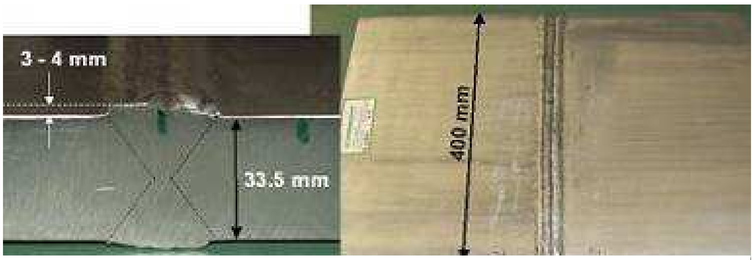

Figure 9: Weld seam

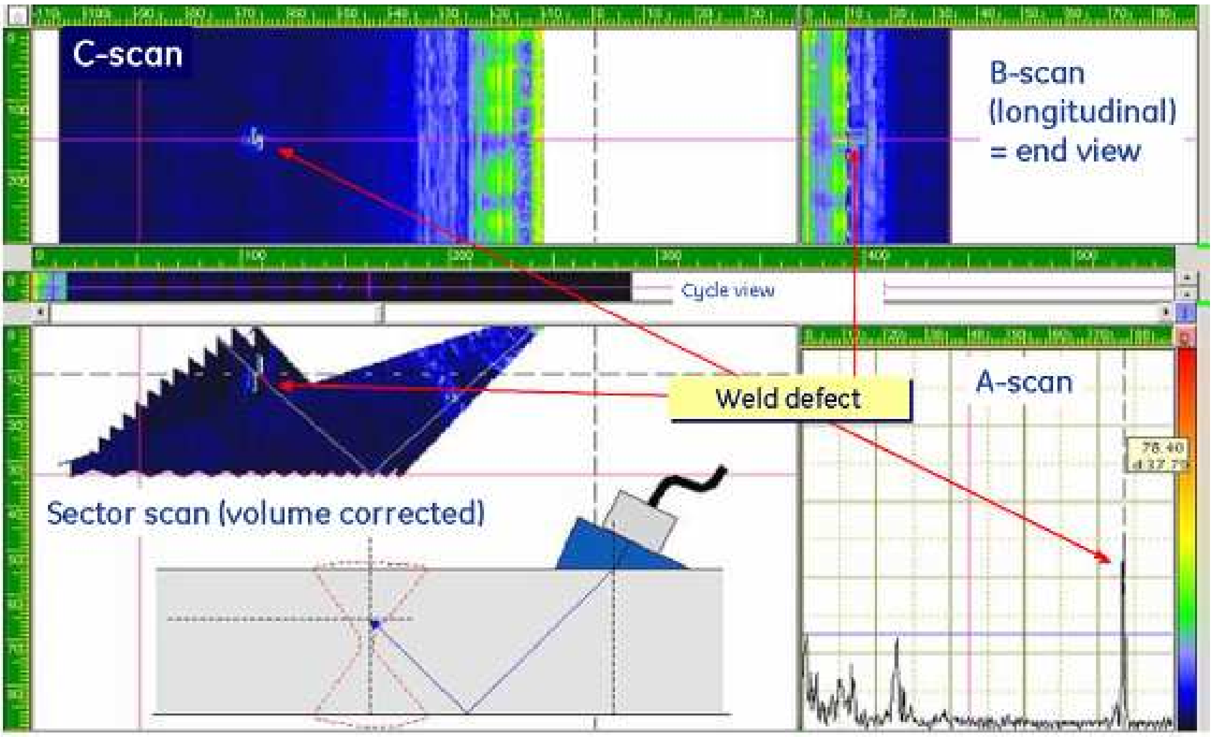

Figure 10: Weld inspection

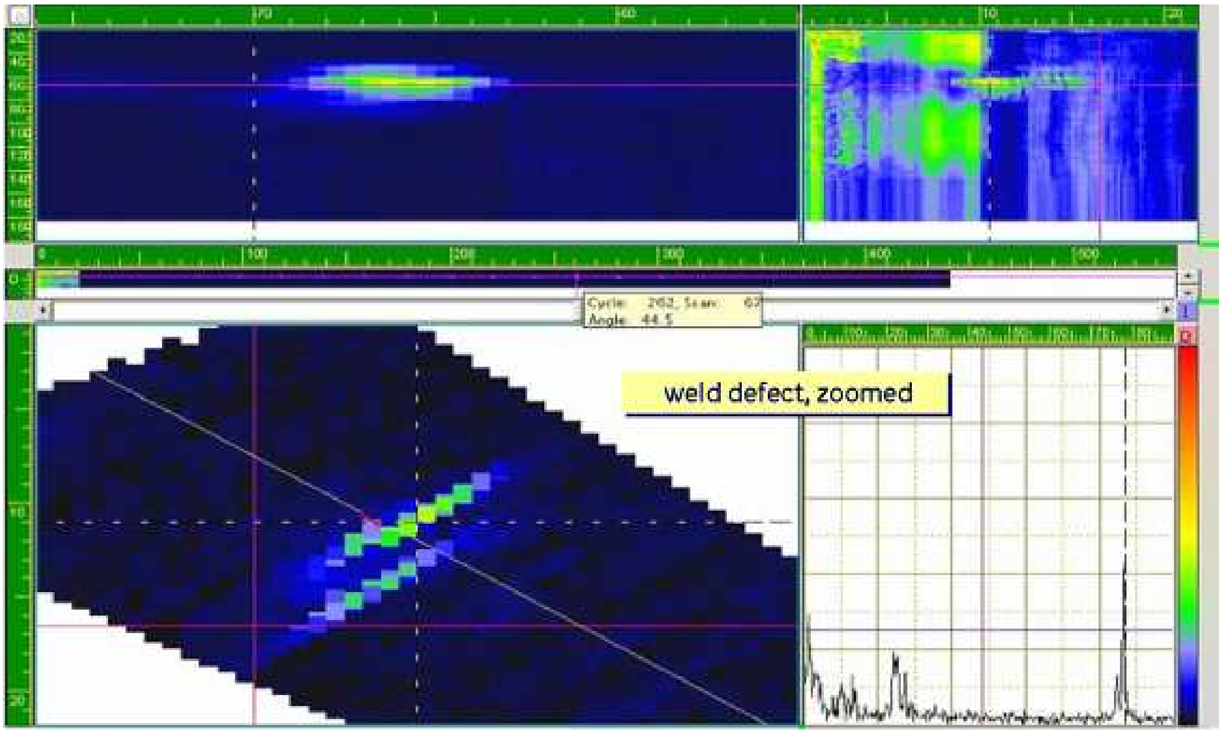

Figure 11: Enlarged view

8. Summary

The results of a Phased Array ultrasonic instrument were presented. The direct, simultaneous representation of the test results as sector scan, C-scan and B-scan in two views (transverse and longitudinal) is the logical development of ultrasonic testing technology in the direction of imaging the test results. However, the requirements of non-destructive testing differ from the scans which are known in medical diagnostics: In addition to the sector scan we also require the further views described here. Conversion to the instrument technology is also more expensive than in medicine because the physics of sound is much more complex in solid workpieces than in organic tissues. The solutions for the application of the phased array technology are already available, thus the conversion to test practice is only a matter of time.