Photoelastic Visualisation _ Phased Array Sound Fields
Part 14 – Phasing Fundamentals

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The video to this article can be seen here: www.ndt.net/search/docs.php3?id=16151&content=1

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1. Introduction

This technical note is Part 14 of a series in NDT.net. Previous notes and videos dealt with the fields and interactions generated by monoelement probes. Part 14 begins what is planned to be a series of notes and videos using phased array systems and probes.

Part 14 begins the process by illustrating how a sound field is build up of “wavelets” from each element in a linear array probe.

The probe used is a nominal 5MHz linear array having 64 elements with a passive dimension of 10mm. Elements are 0.5mm long with a 0.1mm kerf thereby producing a 0.6mm pitch. No refracting wedge is used in this illustration and the probe is paced in direct contact with the glass plate specimen.

Pulsing of the probe is achieved using an RD Tech Focus 16/64 laboratory unit. Pulse width is adjusted to 100ns to provide the optimum output at in a single half-wave negative pulse at 210 V. Other voltages were examined from 150V up to 230V. No increase in signal amplitude was observed after 210V so the 210V pulse was considered optimum.

The glass block specimen is made of soda-lime float glass (compression mode velocity 5850m/s, transverse velocity 3450m/s, density 2.5g/cm³). Through-thickness of the model, parallel to the light path, is 20mm.

Figure 1 illustrates the test setup.
A phased array system allows individual and groups of elements to be fired. Because the elements are all lapped to the same nominal thickness they all have the same nominal natural frequency so the pulse duration is the same for each. Generally, the voltage applied to each element is the same so only the time relative to the first pulse is varied in order to create the beam shape required. Phased array probes operate on the same principles as monoelement probes; i.e. the piezoelectric and inverse piezoelectric effect. The piezoelectric effect is a reversible process. This means that materials exhibiting the direct piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force) also exhibit the reverse piezoelectric effect (the internal generation of a mechanical strain resulting from an applied electrical field).

The inverse piezoelectric effect is used in production of ultrasonic sound waves by applying a voltage across the element, thereby causing it to change its static dimension. Over a limited range of voltage this effect is linear. This means that as the voltage applied is increased the dimensional change of the element is directly proportional to the voltage. When coupled to a test piece, the dimensional change of the element causes a particle displacement of the material it is coupled to and a pulse is formed in the material. In a monoelement probe the particle displacement of the pulse is only that which can be transferred from the face of the element to the test piece. When using phased array probes, the particle displacement in front of a single element is similarly proportional to the applied voltage; however, in most applications we do not use a single element but instead group several elements together and time the pulses from each so that the adjacent wavefronts of each element arrive at a point where the peak particle displacement is at the same point in its cycle as its neighbour. When two such wavefronts meet, the point where they have the same amplitude and phase results in a particle displacement that is the sum of the amplitudes of the two wavefronts.

Therefore, for an applied voltage, the particle displacement of a phased array pulse will be twice the amplitude of the pulse detected by a monoelement probe.

The associated video demonstrates the construction of the phased array pulse in its simplest form starting with a single element and the “wavelet” that forms as it propagates. Additional elements are added to illustrate the amplification of the pulse by constructive interference of the wavelets.
2. Comments on the Video

The video begins with a pulse formed from a single element (element #9) approximately 1mm into the glass specimen. The motorised strobe-light delay is activated and the pulse imaged over a distance of travel equal to about 5mm.

Figure 2 Element 9 at start of delay and after 0.86 µs delay

The image on the right in Figure 2 indicates 2 arcs. With a velocity of 5850 m/s the compression mode is seen to have progressed to the 5mm depth with a brightness that has a central maximum and fades on either side. The slower transverse mode with a velocity of approximately 3450 m/s is seen trailing the compression mode at about half the distance propagated by the compression mode. It has a faint portion of its arc at the central region but increasing brightness with increasing angle away from the central axis of the beam. (In the photoelastic image, brightness of the pulse is proportional to the local pressure of the beam)

To illustrate the interference effect elements 9 and 7 are activated. Figure 3 illustrates the two small dots of the pulses forming under these elements on the left side of the Figure 3. The point where the two arcs of the compression mode cross, seen on the right side in Figure 3, is seen to be brighter than the single arc in Figure 2. The increase pressure is a result of the constructive interference of the wavelets.

Figure 3 Elements 9 and 7 at start of delay and after 0.86 µs delay

Under equal conditions, doubling the area of a probe should produce a received signal double that of the smaller area probe; i.e. the signal should increase by 6 dB. However, when we monitor the response of the backwall signal from the single element phased array pulse and then add a second element next to it the signal amplitude increases by 12 dB.

Adding more elements the effect of the increased amplitude at the points where the wavelet arcs cross is seen to be even more pronounced. In Figure 4, elements 9, 7, 5 and 3 are fired and the points of crossing are seen to be forming a well-defined plane wavefront.
The probe used has a pitch of 0.6mm. Firing the elements 9, 7, 5 and 3 was done to illustrate the wavelets involved. By firing both the odd and even elements from 9 to 2 (i.e. 8 adjacent elements), the small separation of the adjacent pulses makes the end result very similar to the shape that one would get with a single monoelement probe. Of course the difference would be that the pressure of the phased array pulse at the same point along the sound path would be greater than for a monoelement probe having the same aperture. Figure 5 illustrates the effect of firing eight adjacent elements simultaneously.

In Figure 5 the intensity of the individual pulses is such that they cannot be individually resolved on the image and the combined effect is that of a monoelement probe of exceptionally high particle displacement capability.

For more information about the photoelastic system see www.eclipsescientific.com.

The video to this article can be seen here:
www.ndt.net/search/docs.php3?id=16151&content=1