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CIVA confirms L-mode in SH Shear wave generation

Ed Ginzel[1]
[1] University of Waterloo, Waterloo, Ontario, Canada
e-mail: eginzel@mri.on.ca

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Abstract
Normal incident shear, or SH wave probes are often used to assess shear wave acoustic velocities. These have been particularly useful when dealing with anisotropic steels to assess the degree of birefringence. Another application often touted for their use is ultrasonic testing of austenitic steels where it is considered useful since they are promoted as not mode-converting upon reflection. In spite of the promotion as having no mode conversion to compression waves, anyone that has looked closely at the A-scan when assessing acoustic velocities has seen early-arrival signals that are clearly the result of a compression mode being present. This paper examines the presence of these signals using photoelastic imaging and uses CIVA simulation software to confirm them.

Keywords: ultrasonic, CIVA, SH shear, normal incident shear

1. Introduction

In Krautkramer [1], special consideration was given to the description of the shear mode of vibration. Although all shear mode vibrations can be described as having particle motion at right angles to the direction of wave propagation, the case of the mode generated upon the refraction of an incident longitudinal mode was given the term "transverse" mode by Krautkramer. In fact, we still use that term in more recent literature where, for example, in total focussing method (TFM) we assign modes using by the capital letters LL (for longitudinal-Longitudinal) and TT (transverse-transverse) where TT is referring to shear mode. When a transverse wave is generated with particle motion polarised parallel to the plane of incidence and perpendicular to the direction of propagation it is called a shear vertical wave or SV wave. Note that this requires a frame of reference.
When the wave particle motion is polarised parallel to a plane surface of a specimen, we give it the term shear horizontal wave or SH wave (it is also sometimes referred to as normal incident shear, 0° shear). This terminology assumes that the surface into which the plane wave is being transmitted is horizontally oriented.

In its pure form, the SH wave moves with just horizontal displacements. Langenburg [2] illustrates how the coordinate system defines the concepts of SV and SH. A specimen lattice-coordinate system should be kept in mind when we think about the two types of shear waves.

In a simple XYZ coordinate system, if we imagine the direction of wave propagation as "k" aligned with the ZX axis and at some angle α, particle motion of the shear component will be perpendicular to "k". Any component of the particle motion that has some displacement in the Z direction is considered SV polarised. Particles moving parallel to the Y axis and having no Z component are considered to be SH polarised. These concepts are illustrated in Figure 1.

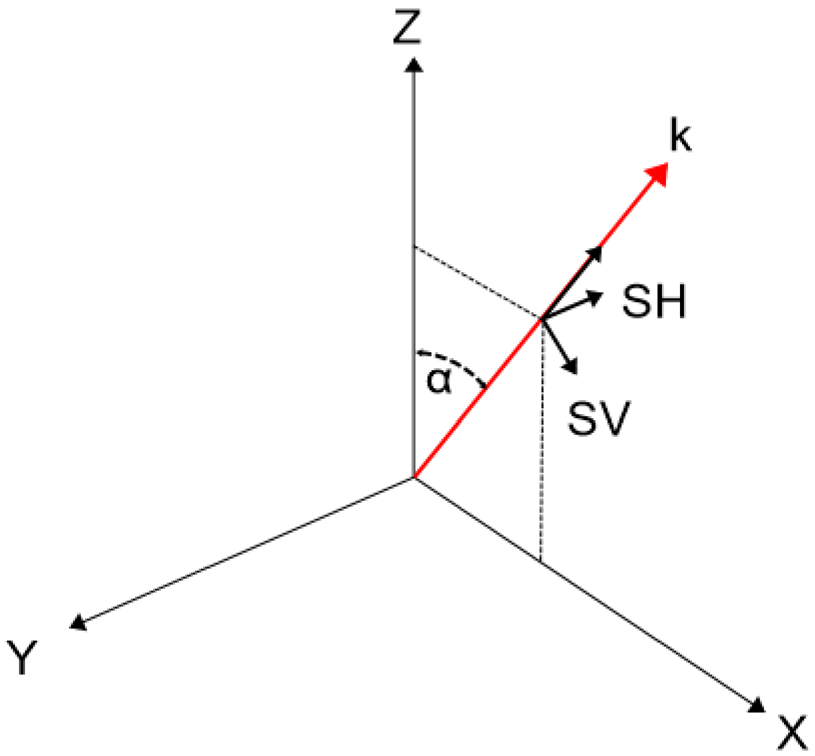

Figure 1 XYZ coordinate system to illustrate particle motion in SV and SH shear modes

Interesting things have been mentioned about SH waves. Ogilvy [3] noted that they provided better results when testing austenitic-stainless steel welds. She noted that compared to SV waves, SH waves suffered less scattering and less beam re-direction as well as having less attenuation and higher sensitivity. Lopez [4] and others point out that SH shear waves do not mode-convert when reflecting from surface boundaries.

It was this idea that SH waves do not mode-convert to longitudinal waves that inspired the author to consider making photoelastic images to illustrate the lack of mode-conversion. In the process of preparing the photoelastic images, it was discovered that this description has a significant limitation. The rest of this paper will attempt to describe the limitations of the idea of SH wave not experiencing mode-conversion.

2. Photoelastic Imaging

When deciding to image the lack of mode-conversion from an incident SH wave on a surface, it was considered a simple matter of transmitting a pulse from a standard shear wave probe into the glass sample with a side drilled hole reflector. A similar exercise has already been done in an earlier paper and photoelastic video [7] where the author noted a weak longitudinal mode had formed upon reflection from the corner of a notch. At that time, it was speculated that a possible explanation for this observation might be that the piezo-elements cannot produce a perfect shear motion and some compression mode is present in the element distortion.

For this project, the photoelastic setup was reconfigured using the same probe as was used in the 2013 project (Panametrics V155 5MHz 12.7mm diameter SH shear) and driven at 375 volts bipolar using a PCPR100 pulser-receiver with 2 cycles. Instead of a flat notch, this time the pulse was directed towards a 5mm diameter side drilled hole.

Photoelastic images (Figure 2) indicate a faint longitudinal pulse precedes the intended shear mode and upon reflection from the side drilled hole the shear mode can be seen to mode-convert with a faint longitudinal mode-converted pulse moving away on either side of the hole.

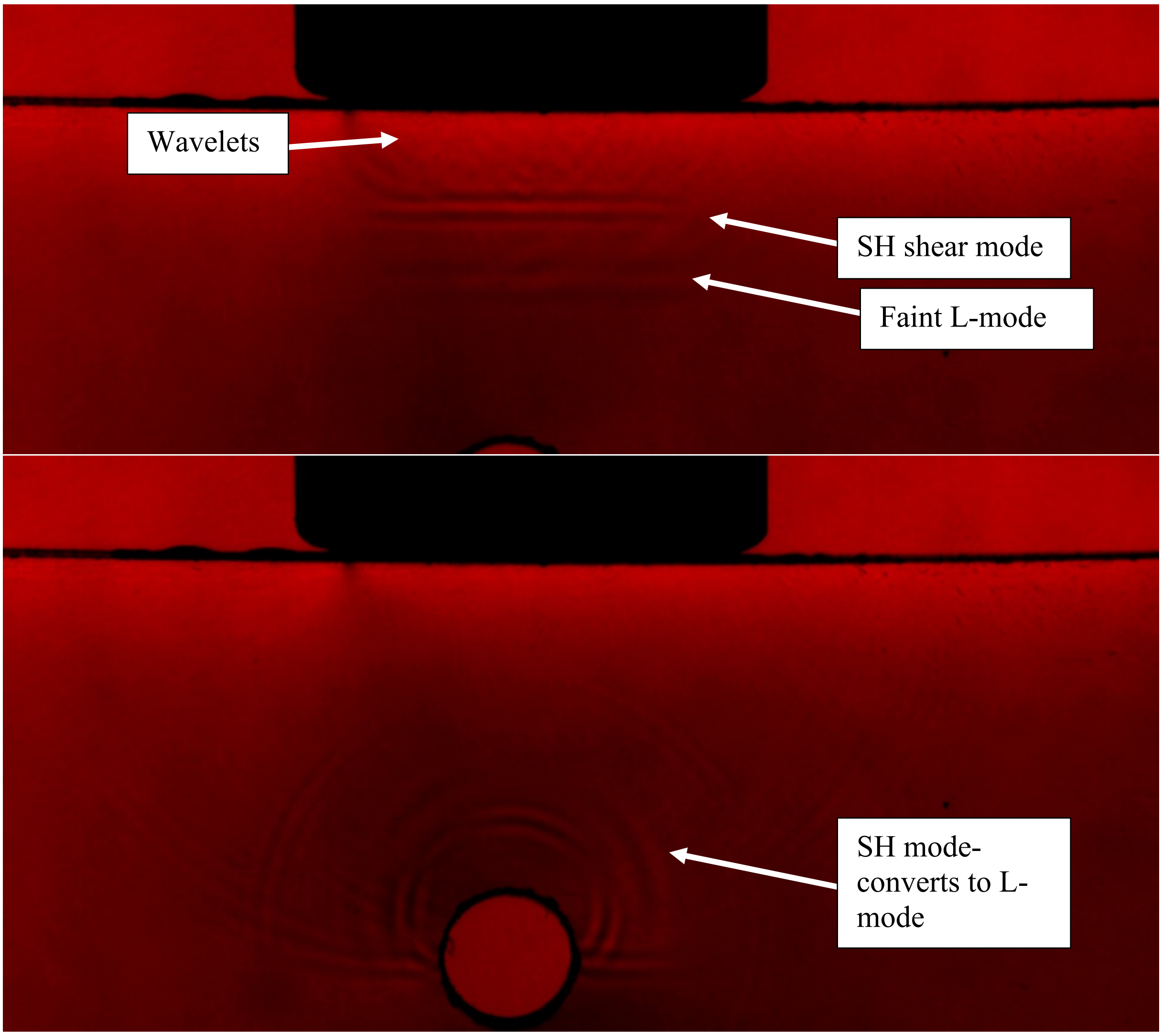

Figure 2 Evidence of L-mode from 5MHz SH shear probe

The effect is more pronounced when using a 2.25MHz SH wave probe (Panametrics V154) as illustrated in Figure 3.

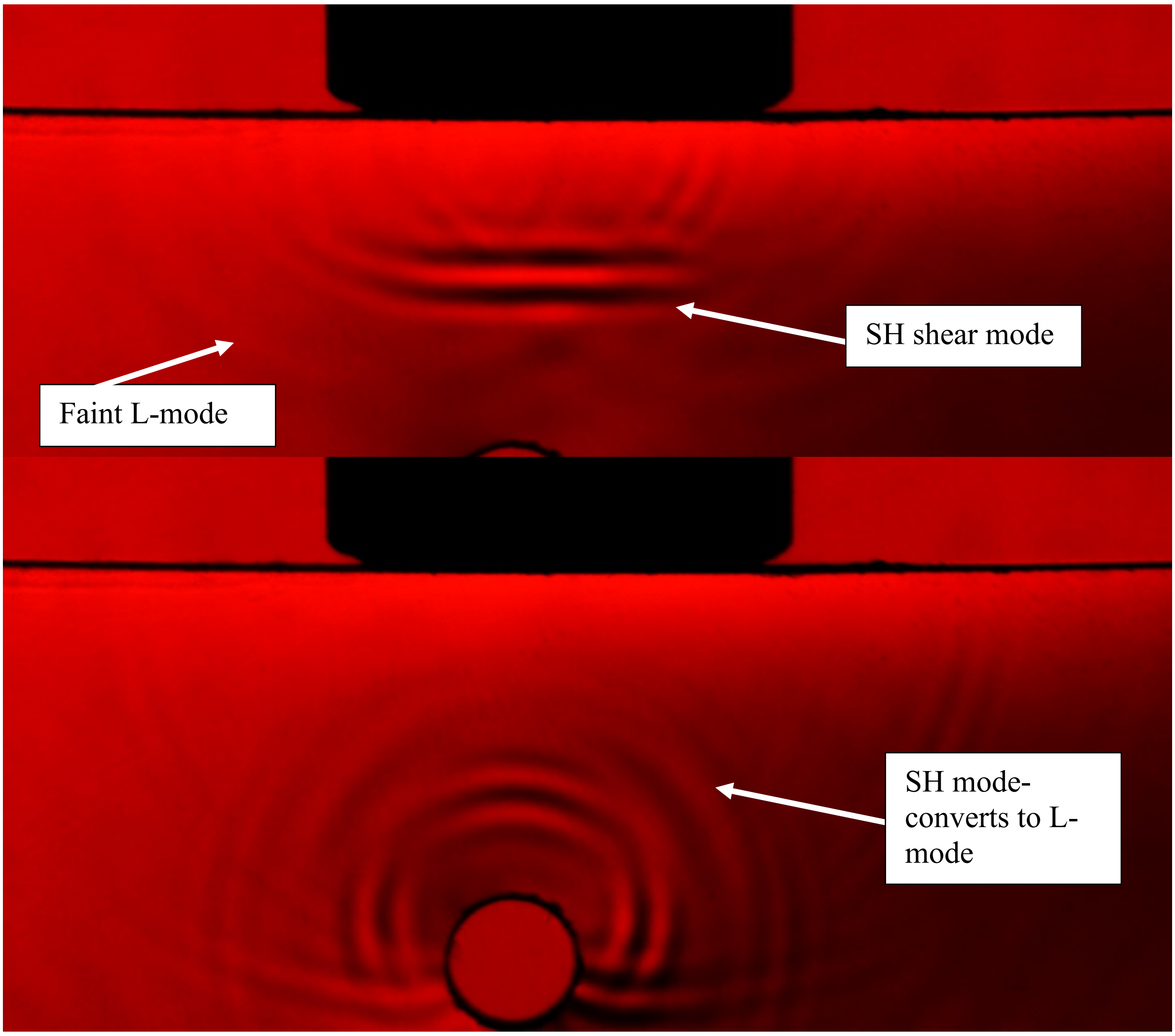

Figure 3 Evidence of L-mode from 2.25MHz SH shear probe

3. CIVA Simulation

In 2025 CIVA released a very advanced edition of the ultrasonic module of the simulation software. This included Finite Element Method (FEM) capability of wave interactions. Leymarie [5] published a detailed description of the processes involved and compared the results of examples using both their traditional ray and the new finite element results of SV shear wave beam models in austenitic welds of thick-walled components. This paper indicated that there is good correlation between the ray (pencil theory) and FEM when the beam intensities are compared.

Although the 2025 edition of CIVA does not have the capability of FEM for an SH shear coupled probe, the semi-analytical version of the ultrasonic module can in fact simulate horizontal shear probe excitation.

A simulation model was therefore configured in the semi-analytical module that duplicated the parameters used for the photoelastic setup. The only aspect that could not be simulated in the semi-analytical model would be Rayleigh waves and for the purposes of identifying the presence of an L-mode in the generation of an SH pulse, the need for Rayleigh wave computation was not required.

The associated videos in this presentation indicate that the CIVA simulation realistically identifies the parasitic longitudinal modes generated by the SH shear probe used in the photoelastic imaging.

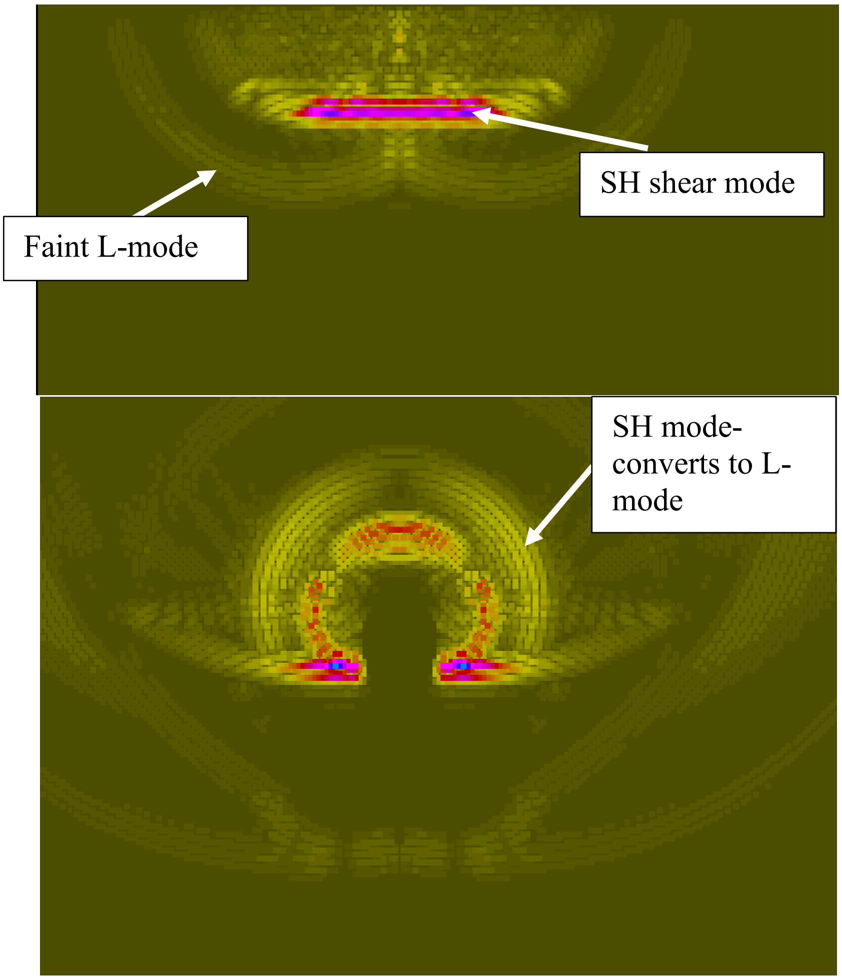

Figure 4 Evidence of L-mode from 5MHz SH shear probe using CIVA simulation

4. Discussion

Figure 5 compares photoelastic and CIVA images where both the photoelastic and CIVA simulations clearly identify the presence of a parasitic longitudinal mode being formed from the SH shear wave transducers.

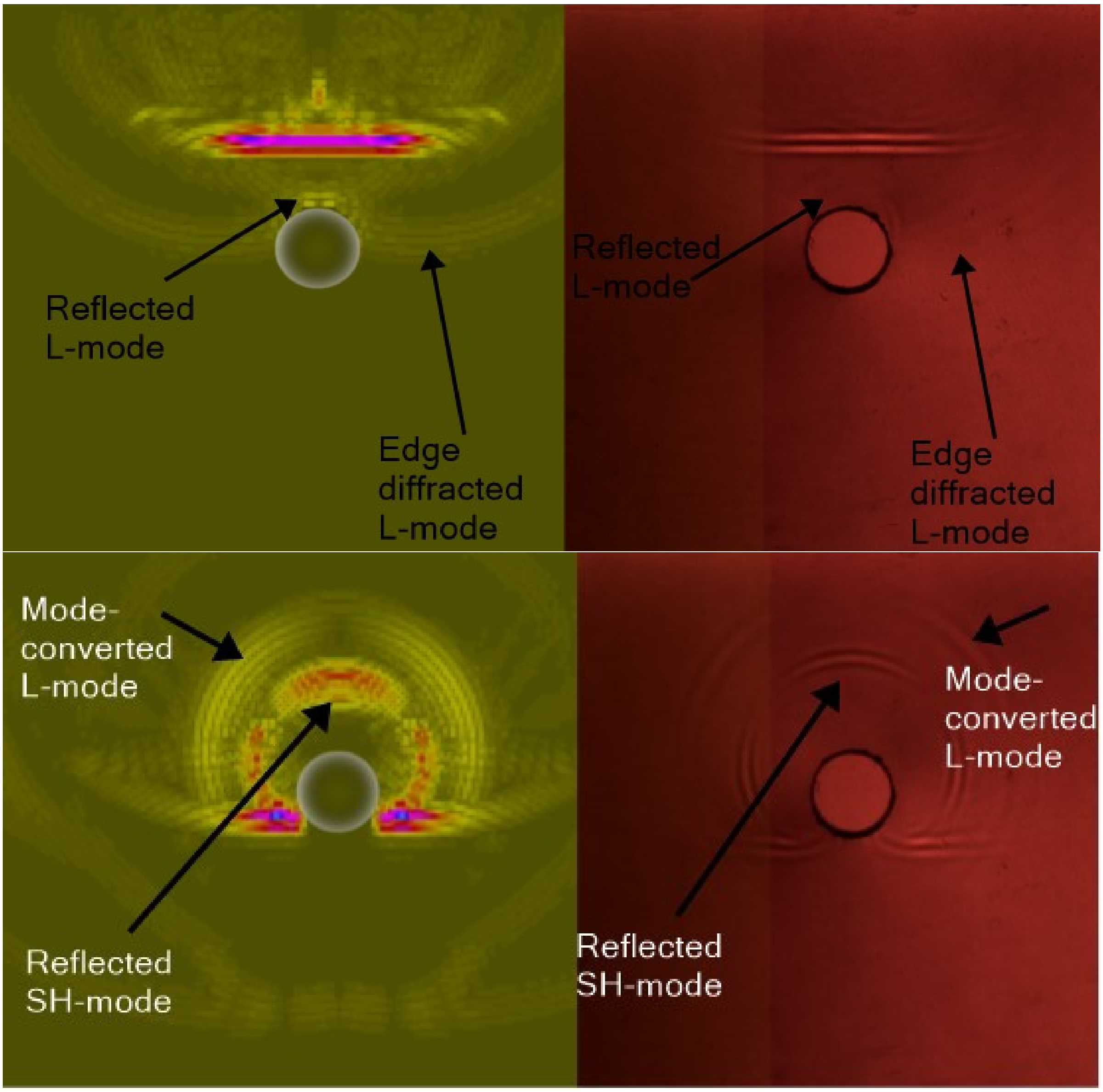

Figure 5 Comparing CIVA simulation of SH shear interaction with photoelastic images

It was considered that perhaps this is a function of the fact that the horizontal shear mode is generated by a piezo-element and perhaps an EMAT produces the pure SH shear mode. However, in discussion with Schmitte [6] it was learned that similar issues arose with EMAT generation of SH shear waves.

An explanation of the origin of these parasitic longitudinal pulses may be identified by observing the arc-shapes of this unwanted mode.

In the CIVA image, L-mode arcs are seen as the pulse is just leaving the transducer. These arcs are centred at the edges of the probe aperture. This can be verified by comparing the arcs at the same point in time for both a 12.7 and 20mm diameter element.
Since there are 2 edges (left and right), two arcs are seen.

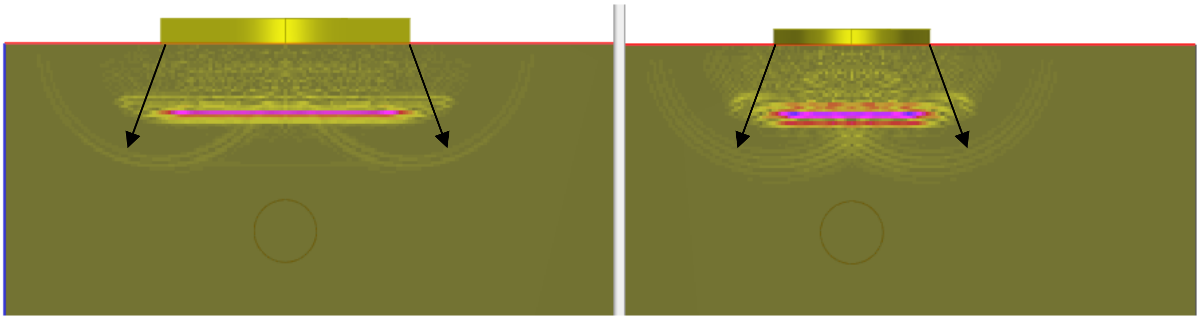

Figure 6 **Parasitic L-mode arcs formed from probe aperture edges (20mm diameter element left, 12.7mm diameter element right)**

The SH probe has a finite aperture. At the edges, the mechanical coupling of the probe terminates and pure horizontal motion cannot be continued past the edge. This essentially forms a point source at the element edge and forces particle displacement to generate as a spherical wavefront. Since the motion is no longer purely shearing, a weak parasitic compression wave forms. This is the same process that causes the parasitic SV shear mode that forms at the edges of the compression mode probes. A lattice representation of a test material's lattice deformation by an SH shear probe is indicated in Figure 7.

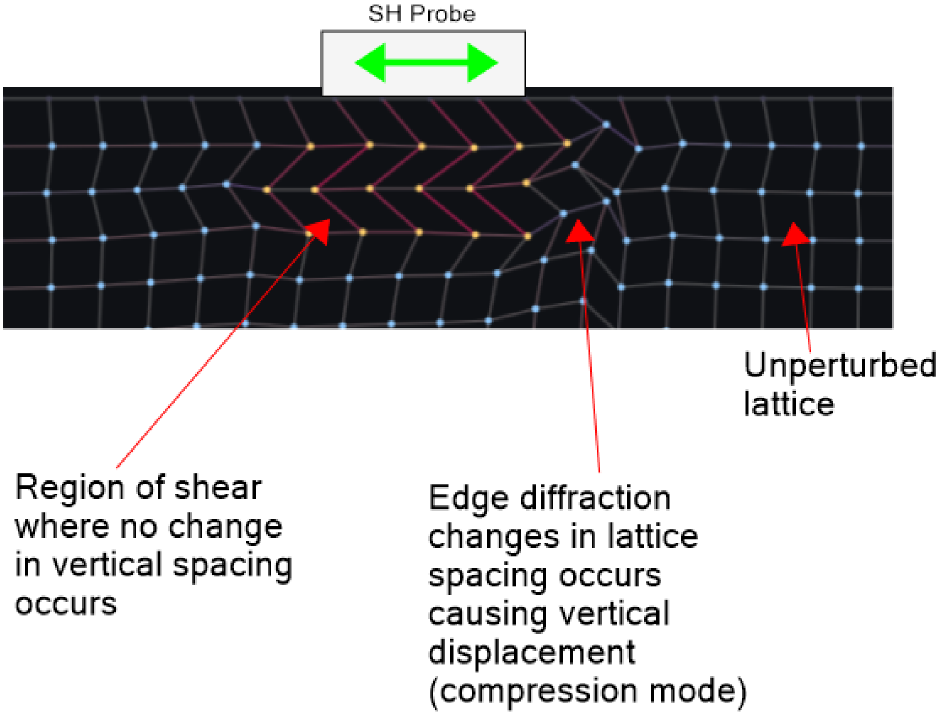

Figure 7 **Simulation of lattice deformation in test materials at edges of probe aperture**

In Figure 2, wavelets are labelled. Discussion with probe manufacturers indicate that SH probes are sometimes made using piezo-composite materials. The slicing and dicing of these ceramics forms "columns" that can be the sources of individual edge diffractors which seem to be the origin of these wavelets.

7. Conclusions

It may be concluded that the longitudinal mode seen in photoelastic images (from both piezo-electric elements and EMATs [6]) is the result of edge-diffractions from the edges of the probe aperture. Since the aperture of any probe is of finite size, they always present edge-diffracted sources of the longitudinal mode. With the slice and dice construction of piezo-composite elements, further diffraction wavelets are generated at the ends of each piezo-composite column.

When seen on the A-scan display (see Figure 8), the L-mode can be seen prior to and just after the intended SH S-mode signals. Figure 8 indicates a screen capture of the 5MHz SH probe on the 25mm thickness of an IIW block.

The interval between the signals indicated as L is 8.42µs which indicates 5938m/s whilst the interval between the signals indicated as S is 15.43µs which indicates 3240m/s.

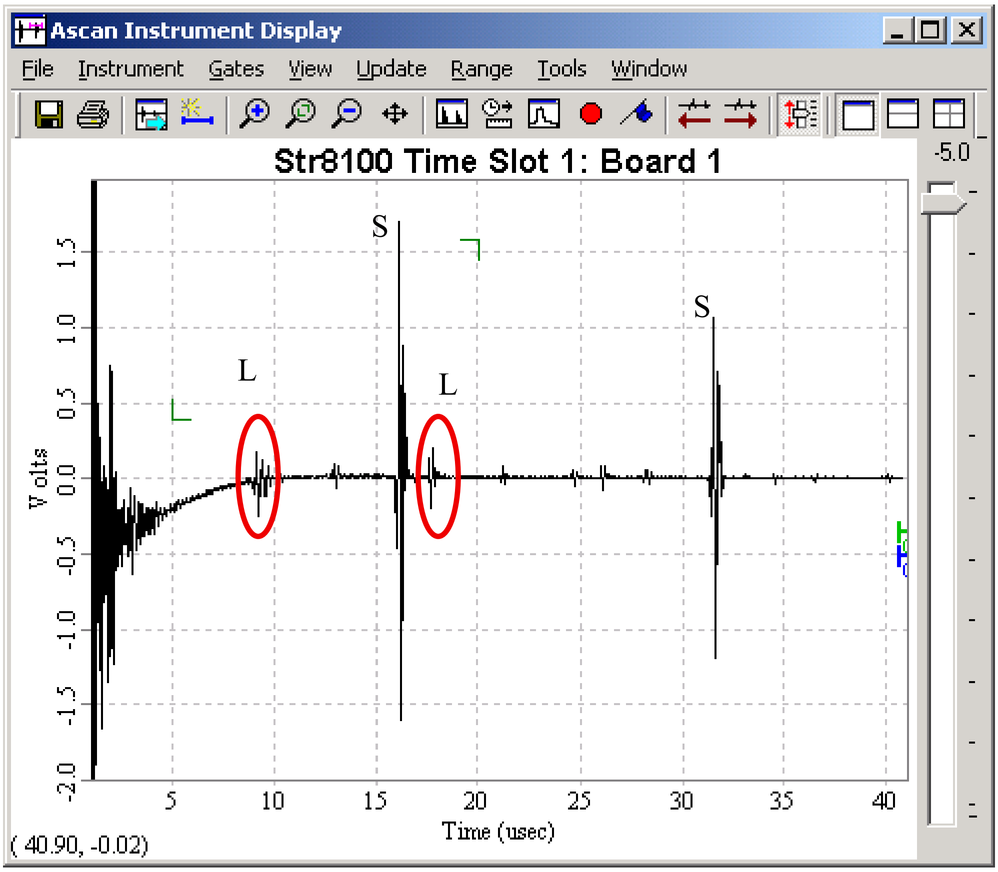

Figure 8 Evidence of L-mode on A-scan of SH probe on the 25mm thickness of Calibration Block 1 (IIW block)

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