All-optical scanning acoustic microscope: rapid phase imaging

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An all-optical version of a scanning acoustic microscope is described. The electronic data acquisition system is a major advance on that previously reported, in that it is now capable of high speed acquisition of phase as well as amplitude images at 82 and 164 MHz.

Introduction: Laser ultrasonics offers many advantages over traditional transducer-based techniques [1]; however, one of its major limitations is that of optical detector sensitivity. Our approach has been to use computer generated holograms (CGHs) to focus and distribute the generating laser light into multiple arcs, thus forming a surface acoustic wave (SAW) focus [2]. The resulting increase in the amplitude of the signal at the focus is extremely important if a practical imaging system is to be realised, since the signal-to-noise ratio must be greater than unity to avoid the use of digital averaging.

In our previous work we have demonstrated rapid amplitude imaging. The phase or velocity of the waves also provides a great deal of information about the material properties, such as coating thickness of thin films, residual surface stress in ceramics, and disbonding of coatings. With this in mind, a modified version of the optical scanning acoustic microscope (O-SAM) has been developed, to image both the phase and amplitude of the surface waves.

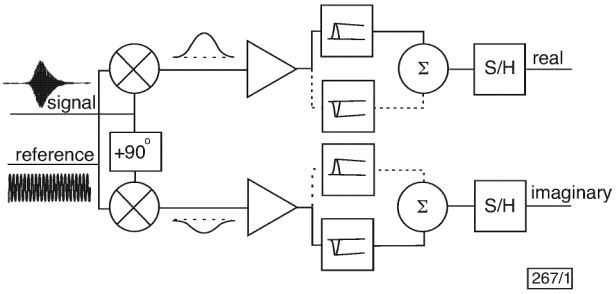

Fig. 1 *Main electronic components of amplitude and phase detection system*

Typical signals shown at key points for clarity

Results: The optical system used to generate and detect the SAWs is described more thoroughly in the previous Letter [3], however some pertinent details are included here for clarity. The ultrasound generation source is a laser producing a tone burst with a fundamental frequency of 82 MHz. The tone burst repetition frequency is 2 to 5 kHz, which determines the upper measurement speed of the system. The light from the source laser is passed through a CGH; this focuses and shapes the light to produce 16 concentric 60° arcs on the sample. The average focal length of the arcs is 2 mm, and the spacing between each arc is one acoustic wavelength at the fundamental frequency of 82 MHz, typically $\simeq 35\,\mu$m on aluminium. The SAWs are then detected at the focus of the arcs by a modified knife edge detector.

The detection of phase and amplitude is achieved by using two double-balanced mixers in quadrature, with a coherent reference signal being provided by the modelocker used in the generation laser cavity. Each mixer produces envelopes the peak amplitude of which is proportional to both the amplitude of the SAWs, and the cosine of the difference in phase between the signal and the reference: $A_{op} = A_{ip}\cos(\phi_{sig} - \phi_{ref})$. With the two mixers operating in quadrature, the resulting outputs are the real and imaginary components of the complex amplitude of the acoustic waves.

There are four key issues in sampling the outputs from the mixers. Their output envelope can vary in time from the trigger pulse (activated by the firing of the source laser) by as much as ±200 ns if the ultrasound detection point is moved relative to the generation arcs. The *peaks* of the mixer outputs must therefore be detected and held for sampling at a point a few microseconds later in time. The peak detector must be *bipolar* to account for the positive and negative envelopes. It is important in particular to minimise any *dead regions* around zero volts – traditionally due to diode forward voltage drop – since this would result in the system being unresponsive to changes in phase around the quadrature points. Finally, the two 'arms' of the system must be very well balanced in terms of gain, offset, and phase difference, to minimise *amplitude/phase crosstalk*. This is because in many situations both the amplitude and phase of the SAWs change, for instance as the O-SAM scans over a crack, and it is important to be certain that an apparent change in phase is not simply the result of a reduction in the signal amplitude.

The developed strategy, as shown in Fig. 1, is a pair of modified diode-compensated unipolar peak detectors – one for positive peaks, the other for negative peaks – the outputs of which are then added together and held by a sample and hold device.

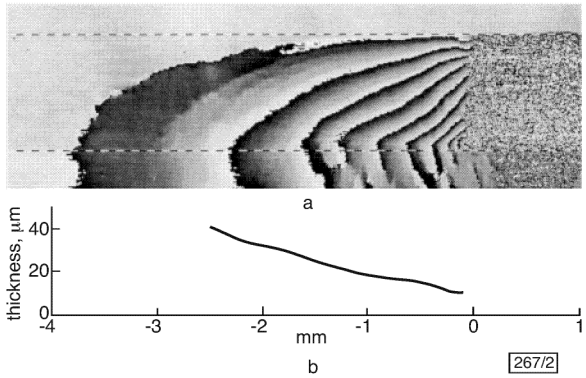

Fig. 2 *Phase image at 82 MHz of subsurface void and thickness of aluminium above the void measured by velocities of dominant Lamb wave modes*

a Subsurface void
– – – void, image size 5 × 1.6 mm
b Thickness of aluminium

Fig. 2 is an example of what can be achieved with the system. Fig. 2*a* is a phase scan of a region around a sub-surface 1 mm-wide slit of varying depth milled into the back of a piece of aluminium, its position is denoted by the dashed lines. The void is closest to, and eventually breaks, the surface on the right. The SAWs in this image are propagating from top to bottom.

Since the source arcs and detection point are a fixed distance apart, the phase is constant in areas where the velocity of the SAWs is constant (the Rayleigh wave velocity). Where the SAWs are converted to two Lamb wave modes [3] a shift in phase is noted, owing to the difference in velocity. Two dominant modes (a_0 and s_0) are present and, since the system acquires the *complex* amplitude, their velocities relative to the Rayleigh velocity can be directly determined by Fourier transformation. By matching these velocities with theoretical velocities for different thicknesses of material [4], a highly accurate depth profile may be obtained, as in Fig. 2*b* – this matches well with the dimensions obtained from the machining process. This would not be possible using a contact SAM, since propagation distances are much smaller, and the liquid couplant severely damps at least one of the Lamb wave modes.

The image consists of 80,000 points, and took five minutes to obtain. Amplitude and phase images at different frequencies (e.g. 82 and 164 MHz) and an optical image may all be obtained simultaneously.

Conclusions: The O-SAM provides an attractive alternative to contact SAMs. The longer propagation length of the acoustic waves allows for mode conversion to be observed readily, and the lack of a [damping] couplant allows for quantitative amplitude measurements and observation of nonlinear (as well as linear) SAW interaction with materials. The simple analogue electronics renders expensive, slow digital acquisition equipment unnecessary for routine scanning.

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References

1 SCRUBY, C.B., and DRAIN, L.E.: 'Laser ultrasonics, techniques and applications' (Adam Hilger, Bristol, 1990)

2 CLARK, M., SHARPLES, S.D., SOMEKH, M.G., and LEITCH, A.S.: 'Non-contacting holographic surface acoustic wave microscope', *Electron. Lett.*, 1999, **35**, (4), pp. 346–347

3 SOMEKH, M.G., SHARPLES, S.D., and CLARK, M.: 'Lamb wave contrast in non-contacting surface acoustic wave microscopy', *Electron. Lett.*, 2000, **35**, (21), pp. 1886–1887

4 VICTOROV, I.A.: 'Rayleigh and Lamb waves: physical theory and applications' (Plenum Press, New York, 1967)