

SAW IMAGING IN ANISOTROPIC MEDIA

M Clark, S D Sharples and M G Somekh
Dept of Electrical and Electronic Engineering
University of Nottingham, University Park,
Nottingham NG7 2RD, UK.

INTRODUCTION

Laser ultrasound techniques [1] have many attractive properties, including non-contact, non-destructive and remote measurement of material properties. However most non-destructive laser ultrasound techniques are too slow to be useful for imaging.

We have built a fast scanning Rayleigh wave microscope capable of scan speeds of up to 1000 measurements per second. The scanning speed is at present limited by the scan stages to a practical speed of up to 250 points per second. At lower speeds averages of many measurements can be taken at each point.

The system is very successful on isotropic materials, less so on anisotropic materials. On these the anisotropy can distort the Rayleigh wavefront and cause signal loss. In this paper imaging is demonstrated on both isotropic and anisotropic materials.

EXPERIMENTAL SETUP

A mode-locked Q-switch Nd:YAG laser is used with a Computer Generated Hologram (CGH) to generate Rayleigh waves on a sample surface. These are detected using a specialised knife-edge detector. Figure 1 shows a schematic diagram of the equipment.

The laser light is delivered to the sample surface by a CGH. This focuses and shapes the laser beam to produce a 60° arc of light on the sample surface.

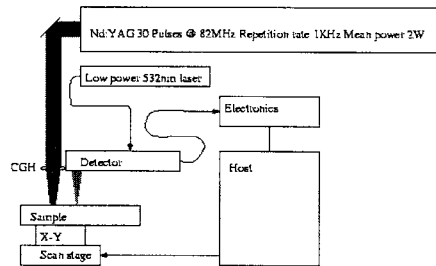


Figure 1. Schematic diagram of the SAW microscope

The use of an arc generation source produces Rayleigh waves with a circular wave front, these propagate to a focus at the centre of the arc. The width of the focused Rayleigh wave can be estimated from the NA of the arc (≈ 0.5) and the wavelength of the focused Rayleigh wave. This system is similar (but *non-contacting*) to the surface wave microscope of Atalar and Koymen [2].

Figure 2 shows the Rayleigh wave amplitude distributions around the centre of an arc generating source for 82MHz and 164MHz. It can be seen that the size of the focus corresponds well to the expected size and that the size of the focus at 164MHz is half of that of the 82MHz signal. The detector uses a knife-edge system, replacing the knife-edge with a split photo-diode.

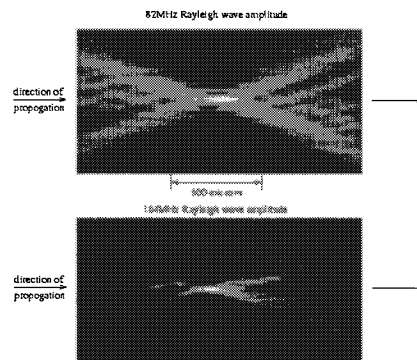


Figure 2. Rayleigh wave amplitude distribution measured around the centre of an arc generation source. The sample was aluminium coated glass. The upper image shows the point spread function at 82MHz and the lower shows the point spread function at 164MHz

IMAGING RESULTS

Figure 3 shows Rayleigh wave images of cracks resulting from a Vickers hardness test on a silicon nitride sample. These were taken at 82MHz and 164MHz using this system at a scan rate of 40 pixels/second taking an average of 20 measurements at each point. The arc radius for these pictures was 10mm. The Rayleigh wave in these pictures was travelling from top to bottom. Distinctive fringes (pitch equal to half the Rayleigh wavelength giving 35 microns and 17.5 microns respectively) can be seen above the horizontal cracks resulting from interference between the incoming wave and a wave reflected from the cracks [3]. The extent of the fringes is limited by the short Q-switch pulse length of the generating laser which limits the length of the Rayleigh wave packet. The width of the fringes and shadow region is greater in the image taken at 164MHz than the image taken at 82MHz, this is thought to result from the cracks reducing in depth towards their ends allowing the 82MHz signal to pass underneath.

With minor modification this system can take velocity images. At present this requires the waveforms to be captured on a digital oscilloscope and this reduces the scan rate to around one point per second. We are working on analog phase sensitive detectors which will allow us to perform fast simultaneous amplitude and velocity imaging.

IMAGING ON ANISOTROPIC AND POLY-CRYSTALLINE MATERIALS

The images shown in figure 3 were taken with a generating arc with a radius of 10mm. This was designed and optimised for imaging on isotropic materials. A key feature of this design is the long Rayleigh wave focal length of 10mm which allows the light energy to be spread over a greater area reducing the peak intensity. With a Rayleigh wave focal length of 10mm the light can be put into a single arc without any surface damage. At shorter focal lengths multiple arcs are required to ensure non-destructive imaging. A long focal length (10mm) is not ideal for anisotropic materials as the waves can be scattered and

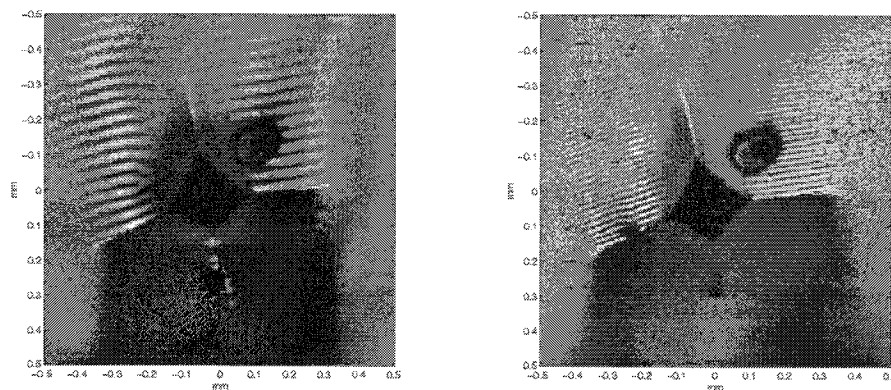


Figure 3. Rayleigh wave amplitude image of cracks around a defect in silicon nitride. The left image was taken at a frequency of 82MHz and the right at 164MHz.

distorted by the anisotropic grains that make up the material. Shorter focal lengths are better suited to imaging on anisotropic materials as they result in less distortion and scattering.

CGHs designed to produce multiple arcs with focal lengths of around 2mm have been used to image on aluminium. In order to remain non-destructive 16 arcs spaced by one wavelength were required.

Figure 4 shows an image taken on aluminium of three subsurface voids. The rightmost void is very close to the surface and blocks the surface waves completely resulting in a distinct shadow region. The middle void is around one wavelength deep and shows distinct Lamb wave fringes over the void [4,5], the leftmost void is more than 2 wavelengths deep and show little or no contrast in the SAW image.

Figure 5 shows an image taken on aluminium of a subsurface void (a slot milled into the back at an angle to the front surface). The image on the left shows the void backed with air, the image on the right shows the void backed with water. In the left image distinctive Lamb wave fringes can be seen [5] on the thin material across the void, these are heavily damped by the presence of the water in the image on the right.

Figures 4 and 5 show little acoustic speckle compared with the similar images shown in reference [4]. This is because of the short SAW focal length of 2mm. This works very well on a weakly anisotropic material like aluminium, however it won't work as well on a more strongly anisotropic material like steel. In this case using an even shorter SAW focal length is not possible because of the increasing likelihood of surface damage and because a minimum distance has to be maintained between the generation and detection points to avoid perturbing the detection area.

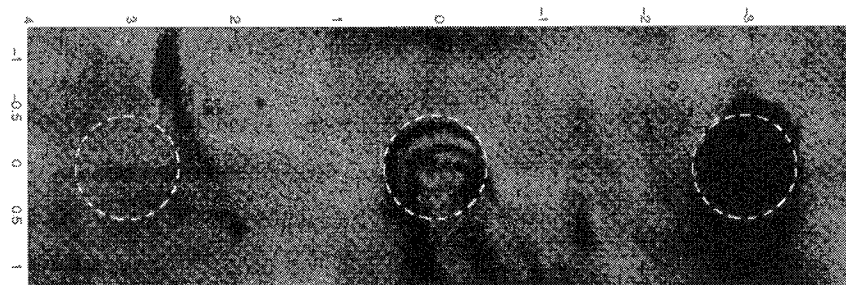


Figure 4. Three subsurface voids in aluminium imaged with 82MHz surface acoustic waves.

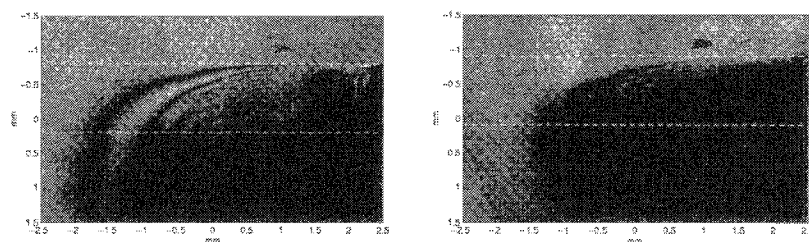


Figure 5. A subsurface void in aluminium imaged with 82MHz surface waves. The void gets deeper towards the left, the surface waves are travelling top to bottom. The void in the left image is backed with air, in the right image it is backed with water. The fringes on the thin material over the void are Lamb wave interference fringes, the Lamb waves are heavily damped in the right image. This sort of contrast would not be possible with a SAM as the couplant would attenuate the Lamb waves.

ADAPTIVE OPTICS/ACOUSTICS

We propose an adaptive system for materials where anisotropy causes speckle and the SAW focal length cannot be made shorter. Figure 6 shows a schematic diagram of such a system. This uses an array of detectors to determine the acoustic wavefront in the focal region where the signal is high. Where the wavefront deviates from the ideal because of the material anisotropy a correction is applied to the generating profile. The generating profile is produced using a spatial light modulator rather than a CGH. This enables adaptation of the generating profile and some correction of the SAW wavefront.

CONCLUSION AND FURTHER WORK

This paper has reported a new SAW scanning microscope. This uses optical generation and detection and is non-contacting. The microscope uses a computer generated holograms to deliver and control the generating laser beam and as a result we can achieve good detection signal levels without any surface damage. This allows us to use analogue electronic amplitude detectors and means we can take measurements at the full repetition rate of the generating laser (currently 1kHz). Presently the scan rate of the microscope is limited to 250 points per second by the scan stages. The ability of this microscope to image surface and near surface cracks and voids has been demonstrated on silicon nitride and aluminium.

This technique is useful in its present form as an imaging tool for the inspection of isotropic materials. On weakly anisotropic materials the imaging can be achieved with little or no speckle provide a short SAW focal length is used.

On strongly anisotropic materials we propose to use an adaptive acoustics approach to correct for the aberrations caused by the anisotropy and grain structure of the

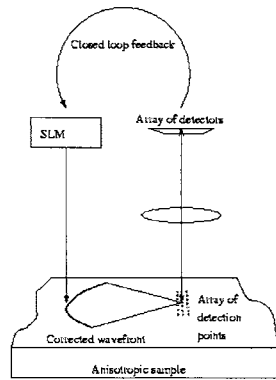


Figure 6. Schematic diagram showing an adaptive acoustic system. The array of detectors is used to sense the acoustic wavefront in the high amplitude region near the focus and this information is used to apply a correction to the generation profile.

materials. We intend to implement these adaptive acoustics approach shortly and are developing novel techniques for wavefront sensing and adaptive generation of SAWs to make higher order wavefront corrections.

REFERENCES

1. C B Scruby and L E Drain. *Laser Ultrasonics, Techniques and Applications* (Adam Hilger, Bristol, UK, 1990)
2. A Atalar and H Koymen, UFFC Transactions, 34 (11), 52-63 (1987)
3. K Yamanaka and Y Enomoto, J. Appl. Phys. 2 846-850 (1982)
4. Matthew Clark, Steve D Sharples and Mike Somekh. UFFC Transactions, Accepted for publication 1999.
5. Matthew Clark, Steve D Sharples and Mike Somekh. Electronics Letters, In submission 1999.