IMAGING FLAWS CLOSE TO SURFACE USING FOCUSED SURFACE ACOUSTIC WAVES

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ABSTRACT

The resolving power and detection ability of the focused surface acoustic wave (SAW) imaging modality is investigated in this paper. In this mode of imaging, conical bulk acoustic waves are used to generate and focus leaky surface acoustic waves on smooth surfaces of materials. Imaging systems built using this technique has diffraction limited focusing property.

An imaging system using this focusing principle has been built, operating at 1.5 and 20 MHz. A slow mechanical scanning system controlled by a personal computer scans the surface of the object, and the data is acquired by the computer to generate a color or a black and white image on its graphic screen. The results of the initial experiments show that the imaging system is very sensitive to the grain structure and possible residual stresses on the surface of the object. It can resolve subsurface gratings of spacing less than a SAW wavelength very close to surface. The imaging system is inherently zero background, providing a high sensitivity not found in similar systems.

I. Introduction

Focusing SAW on flat surfaces of materials using conical waves have been demonstrated [1]. In this method, planar bulk acoustic waves in a liquid are reflected from a parabolic cylindrical surface of a metallic mirror to obtain waves with conical equal phase surfaces, thus forming an axicon. The metallic mirror must be placed perpendicular to the surface under investigation. In fact, any linear axicon whose cone axis is perpendicular to the object surface can be substituted. With such a configuration, all the wavelets hit the object surface at the same angle. If this angle is adjusted to be the Rayleigh critical angle, SAW on the object surface will be excited with a high efficiency. Fig.1 illustrates the waves at various stages of reflection and SAW generation process. Because the intersection of a cone with a plane perpendicular to the cone axis is always circular, generated SAW wavefronts will be circular arcs with diminishing radius, as depicted in Fig.1. Hence, almost all of the energy is concentrated at the point where the cone axis intersects the object surface. It may be shown that this point is a diffraction limited focus. Any irregularity or inhomogeneity at this point will cause reflection or scattering of SAW. The leaky portion of the reflected SAW will reconstruct a diverging conical wavefront and can be detected by the same transducer-mirror configuration.

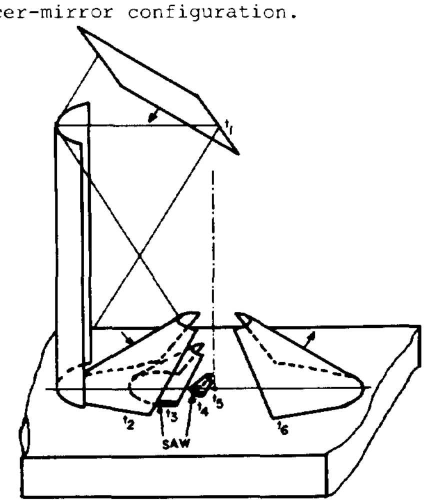

Fig.1. 3-D view of the geometry showing the SAW generation and focusing mechanism by means of conical waves.

Normally, the system is used in pulse-echo mode, and in this mode, it is a zero-background system. In other words, no signal will be received, if there is no SAW reflector on the object surface. The overall efficiency of conversion, from bulk waves into SAW and back into bulk waves, is about 70%. This configuration can be used to obtain a SAW image of the surface if a mechanical scanning arrangement is incorporated.

In this paper, we present images obtained with such a scanning and focusing system generating SAW at two different frequencies. The presented images indicate the sensitivity of the system to flaws very close to the surface, to grain structure and to residual stresses on the object surface.

II. SAW Imaging System

It was shown that [2], there is an optimal mirror size for a particular object material at the given frequency. Two conical wavefront generators are designed and built, one at 1.5 MHz, the other at 20 MHz, both optimized for aluminum. A simple electronic circuitry drives the transducer with pulses and amplifies, gates and detects the reflected pulse to form the output video signal. The dynamic range of the system at 1.5 MHz exceeds 60 dB whereas at 20 MHz it is about 20 dB. A slow scanning mechanical X-Y stage is used to scan the transducer-mirror configuration over the surface of the object, all immersed in water. The stage is controlled by an IBM-XT compatible computer. Although the speed of scanning achieved is not particularly fast, the minimum step size in both X and Y directions is 10 micrometers, providing a fine resolution for data acquisition for 20 MHz operation. The same computer acquires the image data from the receiving electronics through an ordinary A/D converter add-on card with 8-bit resolution, and forms the image on a high-resolution color monitor. The color monitor and associated video card has a resolution of 640 by 400 with 16 colors. It is also possible to obtain images from a dot-matrix printer.

III. Experiments

Aluminum surfaces with natural and artificially induced inhomogeneities are scanned to test the performance of the imaging system.

The sensitivity of the system to grain structures is investigated on an aluminum test piece. The polished flat surface of the drawn aluminum piece is scanned in two directions, one along the direction of drawing and the other, perpendicular to that direction. The images obtained are shown in Figs.2 and 3. The repeatable periodic structure seen on the images is unlikely to be a electrical interference effect, because, the height variations on the object surface are much smaller than a wavelength. The structure is not directly related to surface or subsurface topology, but it is suspected to be a speckle effect: Small scatterers within the focal spot cause SAW reflections with varying phases. These reflections interfere with each other to form the observed speckle pattern. Although the resulting pattern is object dependent, the information is not easily extracted. Note that

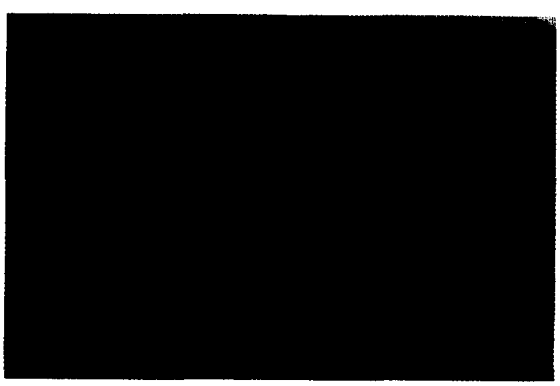

Fig.2. SAW image of the surface of polished drawn aluminum where SAW is focused along the direction of drawing (wavelength = 2 mm).

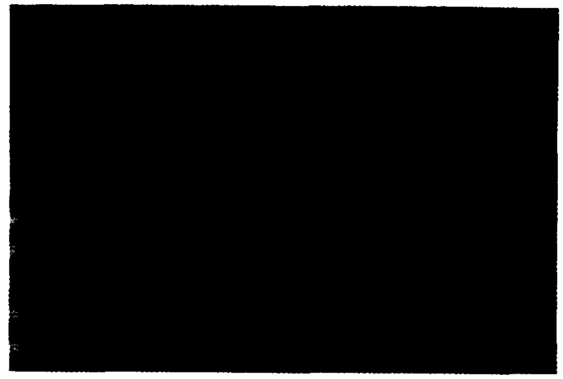

Fig.3. SAW image of polished drawn aluminum where SAW is focused perpendicular to the direction of drawing (wavelength = 2 mm).

the two images are different from each other. When the direction of SAW propagation is perpendicular to direction of draw, the amplitude variation in the speckle pattern is increased by a factor of 3.5. The amplitude variation is possibly related to the scattering strength. It is reasonable to expect that more SAW reflection will take place when the crystallites are oriented perpendicular to the direction of propagation of SAW.

A special test piece is made to test the sensitivity to induced stresses. The surface of a 6 mm thick aluminum piece is pressed by a 6 mm diameter flat topped steel rod to a depth of 1 mm to induce stress as Fitzpatrick et. al. have done [3]. During this operation the other side is clamped to keep it mechanically unchanged. Next to this pressed hole, a hole of similar dimensions is drilled, for comparison purposes. The drilling operation is expected to induce a smaller stress than pressing operation. Then, the smooth side of the test piece is scanned. The image corresponding to the pressed and drilled holes are depicted in Figs.4 and 5, respectively. Both images indicate presence of holes superimposed on speckle pattern. However, the images corresponding to the same topology are different. One may reason that the difference arises from the induced stresses.

Another test piece is prepared to measure the resolving capability of the system. A grating is made into an aluminum block by drilling holes from the backside such that the hole ends are clear from the other surface by 0.7 mm. The spacings of holes are 2.0 and 1.5 mm. As shown in Fig.6, the system clearly resolves the grating with 1.5 mm periodicity, which is 0.75 of the SAW wavelength. This is the expected resolution, because the f-number of the system is about 0.63.

The penetration ability of the system is tested by means of a test piece, which has holes drilled from the back side with varying clearance from the smooth surface. When the holes have 2 mm diameter, that with 3.0 mm clearance was detected as shown in

Fig.4. SAW image of the surface of aluminum block which is pressed from the reverse side to obtain a zone of induced stress (wavelength = 2 mm).

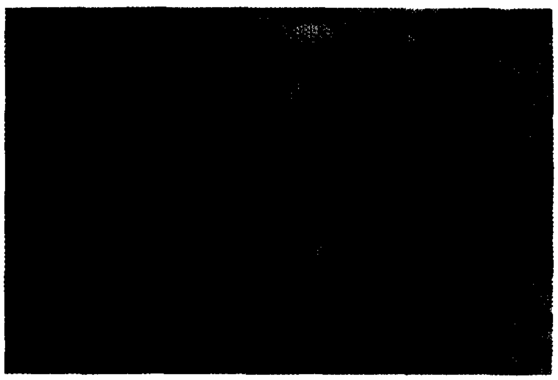

Fig.5 SAW image of the surface of aluminum block which is drilled from the reverse side.

Fig.7. SAW decays to a small value within one SAW wavelength [4], which, in this case, is slightly less than 2.5 mm. On a similar test piece with 6 mm diameter holes, it was possible to sense the 5.5 mm deep holes. Obviously, larger holes produces larger reflections, providing the detection of inhomogeneity almost three SAW wavelengths deep.

The SAW wavelength at 20 MHz is 150 micrometers in aluminum. Consequently the the resolution of the imaging system is higher and the dimensions of the lens is scaled down. In Fig.8, the image of a dent produced by pressing a needle on the aluminum surface is displayed. The width of the dent is measured under a microscope as 250 micrometers.

The subsurface imaging ability of the technique at 20 MHz is demonstrated in Fig.9. A razor blade is bonded to a large piece of aluminum foil by means of phenyl salicylate through the technique described in literature [5]. The other surface of aluminum foil is scanned to obtain the image in the figure. The profile in the middle part of the blade is delineated. The thickness of the foil is 30 micrometers. This thickness is about one-fifth of the SAW wavelength. In this particular case, it is likely that acoustic waves of other modes which exist in plates on an elastic half space, also contributes to the image.

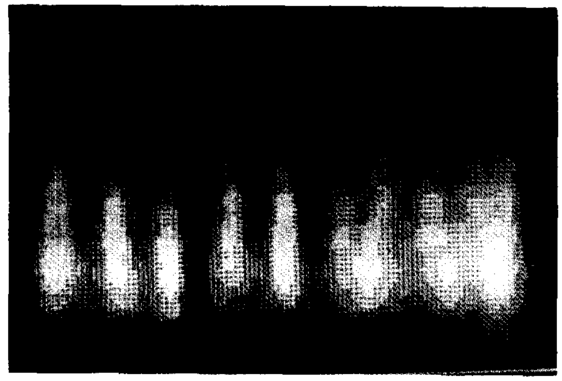

Fig.6. Response of the system to a subsurface grating made up of 0.7 mm diameter holes with 2.0 (left) and 1.5 mm (right) spacing. Ends of the holes are clear from the surface by 0.7 mm.

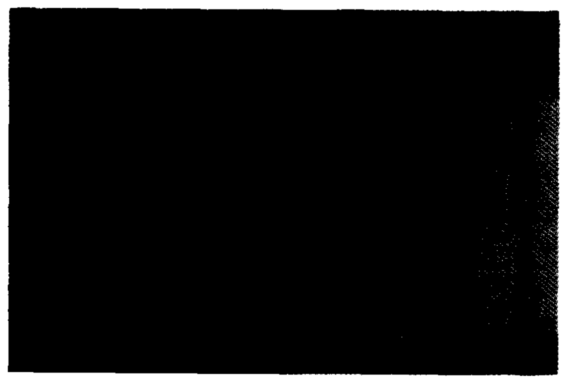

Fig.7. SAW image of an aluminum surface with 2 mm holes drilled from the other side. The clearances of the holes are 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 mm from right to left.

IV. Discussion

This new technique has an important advantage over other modalities in imaging subsurface structures close to surface. By its nature, SAW propagates in a region close to surface, decaying as the distance from the surface increases. Hence, inhomogeneities very close to surface cause a higher perturbation than those away from the surface and therefore they are easily detected. This is in contrast with bulk wave imaging techniques where the finite pulse width limits the detection capability for flaws very close to surface by creating a dead zone.

Fig.8. SAW image of a dent produced by a needle tip on aluminum. (wavelength = 150 microns)

Fig.9. Subsurface image of a razor blade covered by aluminum foil at 20 MHz.

The images generated are purely SAW images, because the system does not excite any bulk waves in the object material. Hence, the images are relatively easy to interpret, free from ambiguity. SAWFAX operates with a high efficiency and the signal to noise ratio of the system is rather high. It is therefore possible to sense the presence of a small scatterer which is several SAW wavelengths deep, by increasing the gain of the video amplifier with a suitable offset.

This mode of focusing produces a focused SAW by making use of the surface of the material under investigation. SAW is first generated on the surface and then focused on a spot. This is better done on surfaces relatively free of inhomogeneities. Hence, the method is most effective on materials with sparse distribution of flaws and minimum structure.

Acknowledgements

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