A PHASE INSENSITIVE ULTRASONIC RECEIVER

Joseph S. Heyman
NASA Langley Research Center
Laboratory for Ultrasonics
Hampton, Virginia  23665

ABSTRACT

Ultrasonic measurements of materials are usually obtained from an electrical conversion of an acoustic signal by a transducer. In this paper, a conventional (phase sensitive) transducer and a new phase insensitive Acoustoelectric Converter called an AEC are contrasted. In particular, the AEC is shown to exhibit superior characteristics for many typical experiments and appears to have many applications in the Nondestructive Evaluation (NDE) area.

Introduction

Transducers that are commonly used in ultrasonics are based on piezoelectric or magnetostrictive conversion of electrical energy into mechanical energy. Major advances in the state of the art of transduction have lead to electromagnetic and electrostatic devices which, although less efficient, have many beneficial attributes. One aspect these devices have in common is that they are phase sensitive. The significance of phase sensitivity is not apparent for laboratory studies on flat, parallel and homogenous samples or for transducer diameters d < \lambda, the acoustic wavelength. But for the case where d > \lambda (megahertz frequencies with conventional transducer geometries) and the "world" of study is not flat or parallel or homogeneous (NDE) phase sensitivity can be a real drawback.

In this paper, the problems of phase sensitivity are discussed and a new phase insensitive transducer called an Acoustoelectric Converter (AEC) is described. Data obtained with conventional and AEC transducers are contrasted for simple pulse echo samples as well as for modified "C" scans of phantom flaws in metal as well as composite materials. The data indicate superior characteristics of the AEC for situations of phase complexity commonly found in a NDE environment.

The Importance of Phase in Ultrasonic Measurements

Recent papers have indicated the important effect phase can have in ultrasonic measurements of material properties.1-4 In addition, measurements of non-parallel samples may be difficult in determining real parameters in complex geometries.5 AEC transducers and AEC transducers are contrasted for simple pulse echo samples as well as for modified "C" scans of phantom flaws in metal as well as composite materials. The data indicate superior characteristics of the AEC for situations of phase complexity commonly found in a NDE environment.

The ABSTRACT of this paper contains approximately 200 words.
measurements which absorbs acoustic energy via free charge carriers. The electric field integrated through the material is lost to the charge carriers.

The second mechanism is related to the Weinreich relation which may be expressed as:

\[
a_{ee} = \frac{\epsilon E_{ee}}{v} \]

where \(a\) is acoustic flux, \(v\) is the acoustic velocity and \(u\) the mobility. This relationship predicts an electric field \(E_{ee}\) to accompany any mechanism which absorbs acoustic energy via free charge carriers. The electric field integrated through the AEC is the output of the device.

The first use of the acoustoelectric effect as a phase insensitive device is reported in Reference 10 by Southgate. Current work on the device at NASA Langley Research Center is focused on NDE while work at Washington University (J. G. Miller) is focused on medical applications.

AEC Characteristics

The directivity (measured with incident "plane" waves) of an AEC is related to its phase insensitivity and, therefore, is a good "yardstick" for comparison with conventional transducers. Therefore, an AEC was fabricated and compared to a piezoelectric transducer in a variable geometry water cell shown in Fig. 6. A conventional phase sensitive transducer was used to generate acoustic pulses as well as to receive the acoustic pulses after they reflected off the AEC face. A laser was used to measure the small angle through which the system rotated. The data obtained from these measurements is shown in Fig. 7. Since the phase sensitive device was used in reflected mode and, therefore, had energy incident at twice the rotated angle, the two transmission curves are the ones to be compared. The structure in the conventional transducer directivity curve is a result of phase modulation.

Another way of looking at the directivity using the water cell of Fig. 6 is to observe a pulse echo decay as a function of angle. This is shown in Fig. 8 for angles 0 degrees through 7 degrees. In each case, the upper trace is the AEC compared to a fixed electronically-generated exponential while the lower trace is a conventional transducer compared to a fixed electronically-generated exponential. Note how rapidly the phase sensitive detector signal degrades with increasing nonparallelism while the AEC signal remains relatively constant. At 0.3 degrees the signal from the conventional device is almost 50 percent down from the parallel condition. No noticeable change is apparent at that angle for the AEC.

The last of the pulse echo pictures represents a nonparallelism of 7 degrees. The AEC response has dropped by about 50 percent. The piezoelectric detector response shows a larger second echo than the first due to phase superposition.

AEC Application

A scanning ultrasonic arrangement similar to the one shown in Fig. 1 was used to compare an AEC receiver to a conventional damped transducer receiver. Several test plates were examined containing phantom flaws. In each case identical conditions were set up with the exception of the receiver used.

The first item scanned is shown in Fig. 9 and is a resolution test plate for ultrasonics. It contains flat-bottomed grooves and holes of various depths with the smallest hole being 1/64th-inch in diameter. Figure 10 is a transmission ultrasonic scan with both traces obtained from a conventional highly damped piezoelectric transducer. The upper trace used a "long" pulse echo excitation technique (narrow bandwidth) while the lower trace used a "short" pulse echo excitation technique (broadband). Both traces show the large grooves but the small holes are almost obscured. Figure 11 is identical to the top trace in Fig. 10 ("long" pulse echo excitation) but obtained with the AEC. Plate resonances are observable in two of the grooves whose thicknesses equalled an integer times \(\lambda/2\). The small holes are clearly visible with a "clean" background and a superior image.

Figure 12 is a photograph of an angled slot resolution plate with three groups of four milled slots. The milling widths are 1/4 inch, 3/8 inch, and 1/16 inch. From the top of the plate down, the milling angles correspond to a depth difference along the slot of 2\(\lambda\), 3\(\lambda\), 0 and \(\lambda/2\), respectively. Therefore, the top slot should contain four regions of resonance, the second two, the third none, and the last, one. As before, Fig. 13 was obtained with a conventional transducer. Although the slots are visible and resonances apparent, the complex structure is obscured. However, replacing the receiver with an AEC produced the picture shown in Fig. 14 which is quite clear shows a smooth entrance into the slots and clearly shows resonance conditions. The background signal is free of noise compared to the conventional transducer figure.

The last sample examined shown in Fig. 15 is an epoxy-graphite composite, a small region of which is internally bonded to a 0.002-inch thick Mylar film. The film acts as a "non-bond" region and shows up clearly in the ultrasonic pictures. Figure 16 shows the conventional transducer image of the composite structure. The background variation indicates considerable structure which most likely is caused by phase modulation. Actual variations in material properties leading to changes in attenuation are difficult to interpret. However, the composite plate as viewed by the AEC shown in Fig. 17 is more uniform. Recalling the directivity plot, the AEC is a "better" picture of the variability of the material. Since the AEC can be calibrated directly for attenuation, absolute measurements are possible thereby indicating more reliable information about the composite structure.
Conclusions

Although phase information can play an important role in some ultrasonic measurements, there are many situations where the phase superposition with amplitude superposition lead to data misinterpretation. The reason for this deficiency is the phase sensitive nature of conventional transducers. When the transducer diameter is larger than the acoustic wavelength, phase modulation can dominate the signal.

A new type of transducer has been developed which we call an Acoustoelectric Converter (AEC) and appears to have application to NDE. Since the AEC is almost a power detector, it is nearly phase insensitive with an output comparable to the sum of the "squares" of a conventional microarray. This provides a resolution enhancement, a high power enhancement and a low power loss. The net result of the AEC is to low down the "grass" associated with conventional transducers with a one-parameter (attenuation) measurement.

Acknowledgement

The author wishes to thank Dr. John Contrell for many helpful discussions concerning this paper.

References


Figure 1. Typical arrangement for transmission ultrasonic imaging showing phase shifted plane waves exiting from the tested material.

Figure 2. Two in-phase acoustic waves incident from the left on a conventional piezoelectric detector resulting in a large electrical output shown on the right.

Figure 3. Two out-of-phase acoustic waves produce a reduced electrical output.

Figure 4. Two frequency shifted acoustic waves produce a severely phase modulated electrical output.

Figure 5. For cases of in-phase, out-of-phase, and frequency shift, the AEC (power detector) output is a constant since the incident power is constant.

Figure 6. Block diagram showing variable geometry water cell.
Figure 7. Directivity data of the AEC contrasted with that of conventional phase sensitive transducers. Both data were obtained in the water cell shown in Fig. 6.

Figure 8. Pulse-echo data obtained in the water cell with angle varying from 0.0 degrees to 7 degrees. The upper conventional traces are from the AEC (power signal) while the lower traces are from the conventional piezoelectric detector (pressure signal).

Figure 9. Resolution test plate containing flat-bottom grooves and holes, the smallest of which is 1/64-inch in diameter.

Figure 10. Transmission scanned ultrasonic picture of the plate shown in Fig. 9 using a conventional phase sensitive transducer. The upper figure (a) is long pulse echo excitation (narrow bandwidth) while the lower trace (b) is short pulse echo excitation (broad band).

Figure 11. Same as Fig. 10(a), but using an AEC for the detector. The smallest holes are clearly visible as are plate resonances in the grooves.

Figure 12. Angle resolution test plate (see text).
Figure 13. Conventional transducer scanned image of the plate shown in Fig. 12.

Figure 14. AEC scanned image of the plate shown in Fig. 12. The magnified region shows the small grooves which are on the left of both Figs. 13 and 14.

Figure 15. Photograph of an epoxy-graphite composite with a built-in regional "non-bond".

Figure 16. Conventional transducer scanned image of the plate in Fig. 15.

Figure 17. AEC scanned image of the plate in Fig. 15.