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THE NDE OF PULTRUDED GRP COMPOSITES USING AIR-COUPLED ULTRASOUND AND EMAT-BASED GUIDED WAVE INSPECTION

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ABSTRACT

Air-coupled ultrasonic measurement techniques can be used for contactless measurements. Here, we demonstrate that they can be used to detect defects caused by impact damage in a pultruded glass fiber composite, which has a highly scattering structure. The images of damage have been analyzed, and the relationship to impact energy determined. The technique is also compared to signals generated via an EMAT device and a non-damaging metal patch attached to the surface of the sample.

Keywords: Air-coupled ultrasound; Non-destructive testing; capacitive transducers; Pulse compression.

1. INTRODUCTION

Air coupled ultrasonic techniques have been investigated in the past as they overcome the complication of using coupling media such as water, gel, oil etc. The application of a coupling medium might not be convenient for some situations such as where the material gets contaminated or where the structure may absorb liquids. Despite the fact that ultrasonic attenuation in air is high, and especially at frequencies above 1 MHz, good signals can be obtained provided there is careful design of the transducers with respect to sensitivity and bandwidth.

The main transducer types that can be utilized for air coupled ultrasonic measurements are piezoelectric and electrostatic transducers. Piezoelectric transducers are intrinsically resonant devices, and need to be impedance-matched to air. Matching layers using materials such as aero-gel and silicon rubber [1] can be used, but it can limit the overall bandwidth of the device [2]. For this reason, other authors have used piezocomposite active elements, where the mismatch is not so great [3].

Capacitive (electrostatic) transducers overcome the mismatch at the air-material interface by use of a thin flexible membrane against typically a rigid silicon or metal black-plate to achieve maximum bandwidth [4], with silicon allowing micromachining techniques to be used.

The motivation of this work is to illustrate that signal processing techniques such as pulse compression can be used to detect defects in pultruded composites Such materials contain typically both continuous glass-fiber mats and chopped fibers, making them difficult material to inspect using ultrasound due to the high level of scattering. The role of pulse compression is to upgrade the signal to nose ratio (SNR) when used in a through-transmission measurement in air.

Another technique that could be used is guided-wave ultrasound. In this paper, some preliminary measurements are also included on the use of Electromagnetic Acoustic Transducers (EMATs), together with an easily-removeable conductive thin metal patch applied to the surface, to generate such waves.

In the following section, the transduction methods are described, before some experimental results are presented.

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2. APPARATUS AND METHOD

2.1 Capacitive transducers

In this work a capacitive ultrasonic transducer pair was used as transmitter and receiver in a through-transmission configuration. The transducers used a micro-machined silicon black plate, as shown in Figure1. These holes are to act as air springs underneath the metalized Mylar membrane.

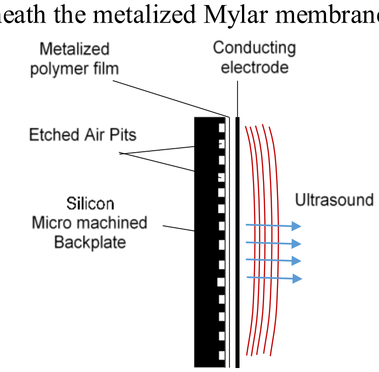

Figure 1: Schematic of Capacitive transducer

The coated back plate is a coating of gold to make it conducting with the membrane grounded connecting to the outer electrode. For the source a transient voltage along with an optional dc bias voltage is applied. As a recipient the membrane moves with the variation in charge provided by the bias voltage. The transducers used for experiment were mounted in the metallic shielded case and approximate diameter of 10 millimeters.

2.2 Ultrasonic pulse compression

The problem of low SNR in air-coupled measurements can be tackled using a resonant device and a high amplitude tone-burst excitation signal. However, such an approach restricts bandwidth and defect detection capabilities. Conversely, wide bandwidth pulse-compression approach achieves an improved SNR in the presence of random noise (such as is present in an air-coupled experiment). In this work a “chirp” signal is used, where the frequency is swept continuously over a predetermined range. The chirp signal can be represented as

$$C(t) = \sin(\omega_s t + \frac{\pi B}{T} t^2), \quad (1)$$

where ω_s is the initial angular frequency, B is the bandwidth of the signal, and T is the pulse duration. A Hanning or Gaussian filter is typically applied to avoid sidebands. Typical drive signals are shown in Figure 2, with a center frequency of 450 kHz.

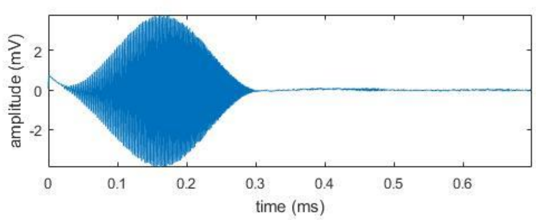

Figure 2 (a): Chirp signal of 3 ms

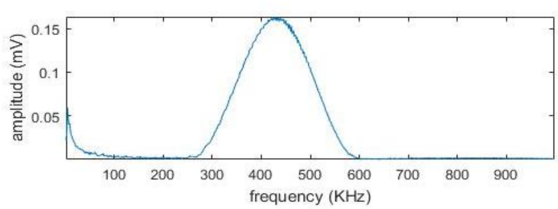

Figure 2 (b): Frequency spectrum of (a).

A pulse compression output $P(t)$ results from a cross-correlation of the received signal $C_t(t)$ with a reference drive signal C_t:

$$P(t) = C(t) * [C_t(t)] \quad (2)$$

The experimental setup used for this work is shown in Figure 3, and uses two capacitive transducers of the type shown in Figure 1, and which can be used as either a source or a detector.

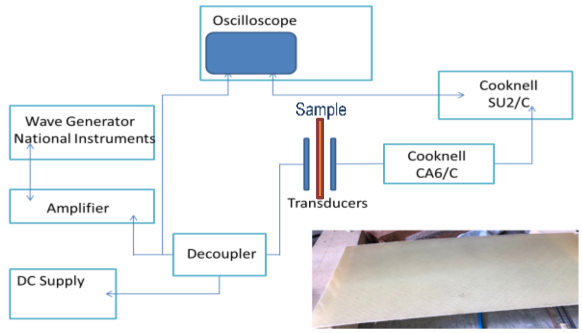

Figure 3. Experimental setup of Air-coupled measurement

The source was connected to a wave generator within a National Instruments PXI system, which fed the source via a power amplifier and a DC de-coupler. The detector was connected to a Cooknell charge amplifier which also supplied a DC bias voltage. The charge amplifier signal was then fed to a digital oscilloscope within the PXI system for recording and cross-correlation. A typical experimental signal observed after pulse compression is shown in Figure 3, showing a good SNR.

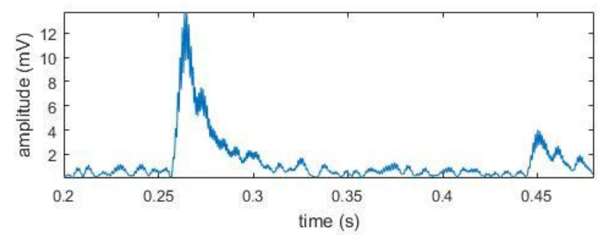

Figure 4. Pulse compression output for ultrasonic through-transmission experiment in a 3 mm thick pultruded GRP composite plate

The transducer pair could then be scanned over the sample using an X-Y stage controlled by the PXI system to record images.

3. RESULTS

3.1 Air-coupled images of pultruded grp plates

The system of Figure 3 was now used to produce images of the plates after being subjected to impact at known energies. The result for an impact energy of 6 J is shown in Figure 5, where the defect is clearly detected. It was observed that there was a complicated dependence of damage area with impact energy – initially, the area of damage has increased at higher energies at low level impacts, but thereafter, at even higher energies, the area of the damaged area in the images changed shape and varied in size. This is illustrated in Figure 6, where a different orientation and type of damage at an energy of 12 J is evident. This underlines the complicated nature of damage and delamination in such composites, where the combination of glass fiber mats, chopped random fibers and polymer with filler.

This complex interaction can be seen when the area of the defective region, estimated from the resultant images, is plotted as a function of impact energy. It is seen that for low impact energies, the defect area within the image increases, but at higher values it does not do so, but tends to oscillate in size. This is an interesting phenomenon, which will be investigated further.

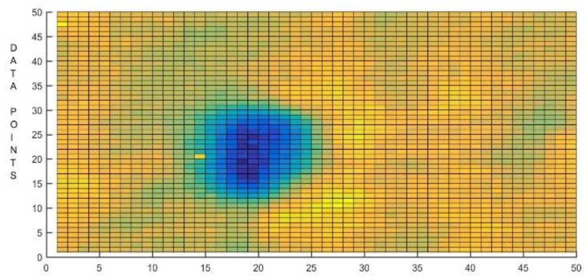

Figure 5. Image for impact at 6 J energy, step size 1 mm each data point (x-y axis)

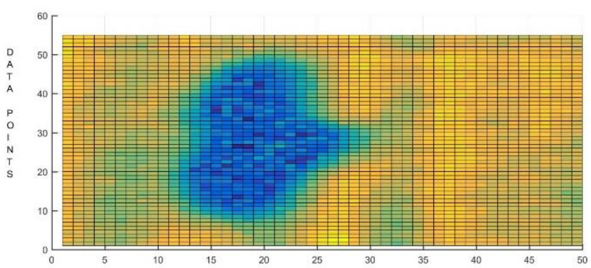

Figure 6. Image for impact at 12 J energy, step size 1 mm, 50 at x-axis, 55 at y-axis

3.2 PRELIMINARY MEASUREMENTS WITH EMATS AND GUIDED WAVES

Experiments have also been performed using an EMAT. Normally such devices cannot be used on electrically-insulating samples. However, in this work we have used thin copper patches which were applied to the sample (and which could be removed afterwards without damaging the surface).

Figure 7 shows a schematic diagram of this arrangement. The EMAT was positioned close to the patched, and a signal recorded as a guided wave is transmitted across the sample, in this case an SH mode (generated using a periodic magnet array to fix operation at one particular frequency). A signal recorded using this arrangement is shown in Figure 8. It can be seen that a clean SH mode signal was visible, and that this was followed by reflections from two sides of the plate.

The interesting point is that this is an independent NDT technique, which interrogates the sample in a different way. We are currently expanding this work to image defects with either through-transmission or reflected signals using a pair of EMATs and various guided-wave modes for comparison to the air-coupled results, and these will be reported at the conference.

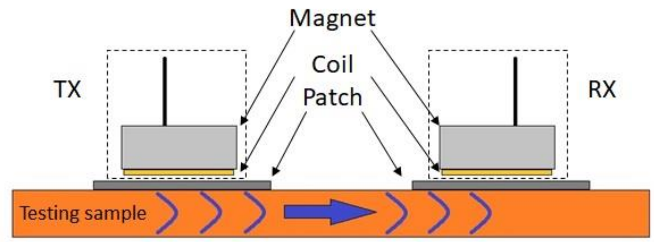

Figure 7. Schematic diagram of the EMAT measurement

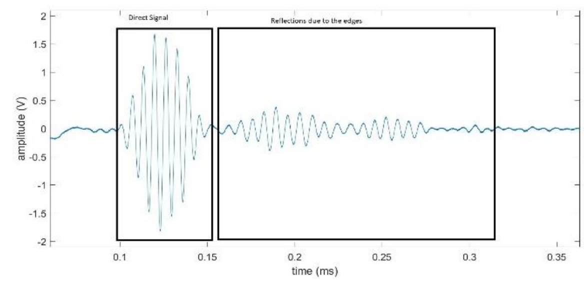

Figure 8. SH guided-wave signal generated with a pultruded GRP plate

4. CONCLUSION

Two different methods have been described for generating signals within a scattering pultruded GRP plate. It is shown that air-coupled imaging gives good results, but also that a guided-wave EMAT approach shows promise. Future work will compare the two techniques.

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