BANDICOOT — A NOVEL APPROACH TO USING A PITCH-CATCH ACOUSTIC PROBE FOR FIELD NON-DESTRUCTIVE TESTING†

Laurence P. Dickinson & Suszanne Thwaites
CSIRO Telecommunication and Industrial Physics, Sydney

ABSTRACT: The acoustic Pitch-Catch probe is commonplace in the world of aerospace non-destructive testing for the location of defects within a composite sandwich panel. However the usefulness of the technique is lacking in many respects, being cumbersome to use and generally very costly. Building on several years of experience, a new approach has been taken by CSIRO to produce a simple and versatile system that incorporates an optimised Pitch-Catch probe within an optical computer mouse and combined with a notebook computer, to provide a fully featured scanning system for a fraction of the cost of systems currently available. This paper describes the approach taken and some of the underlying research in developing the Bandicoot.

1. INTRODUCTION

The testing of composites consisting of a honeycomb core sandwiched between skins of various fibre composite mixtures presents some problems to the use of conventional ultrasonic methods. The impedance mismatch between the skin and core and the thickness of many of these constructions attenuates the ultrasound too much for good transmission or reflection. Thus it has become common to use alternative methods and, in particular, vibrational methods with frequencies less than 100 kHz. A range of such acoustic non-destructive testing (NDT) systems are commercially available and include the use of Pitch-Catch and Mechanical Impedance Analysis (MIA) techniques. Using existing commercial systems for the inspection of in-service damage to aircraft can be complicated and very costly. In many circumstances quantitative NDT cannot be carried out in the field due to the lack of skilled personnel and equipment, with the aircraft having to return to a service centre for inspection.

Traditionally acoustic probes have been used as hand pick-and-place devices . However, recently systems have become available where the probe can be attached to a C Scan system. An example is the MAUS system [1] built by Boeing where a track is attached to the structure by suction cups and the sensor is moved, by hand or automation along the track, allowing positional information to be encoded.

2. PITCH-CATCH ACOUSTIC PROBES

The Pitch-Catch principle is quite simple and widely used in acoustic, ultrasonic and many other wave propagation applications. The concept in its simplest form normally incorporates two transducers, one configured as a dedicated drive and the other as a dedicated receive channel (Hence the terms Pitch and Catch).

The type of pitch-catch probe shown in Figure 1 is typical of an acoustic frequency NDT device. In popular commercial systems the transducers are generally strengthened polarised ceramic bimorphs, consisting of bonded sandwiches of opposing polarised piezo-ceramic disks with a thin metal or ceramic shim between. When a voltage is applied to the transducers, one ceramic element will attempt to expand and the other to contract. This action couples through the adhesive bond to create a bending or flexing mode that achieves a much greater displacement amplitude than could be expected from thickness expansion of the ceramic elements by themselves. The bimorph ceramic disks are normally mounted with their edges free and mechanically coupled to the test specimen via a centrally located contact pin.

Excitation in various commercially available devices is usually a short tone burst or a swept sine chirp within the frequency range of 2 to 70 kHz. Various forms of often quite complex detection and analysis have been used to process the result and produce an output indicative of damage. In general these methods work quite well in that they are sensitive to the defects sought but in fact they are difficult to set up and to calibrate. Whilst this may not be a problem for skilled engineering personnel, it is very difficult to set up a system so that relatively unskilled operators can use it to make pass/fail decisions.

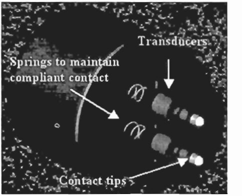

Figure 1. A typical Pitch-Catch probe configuration

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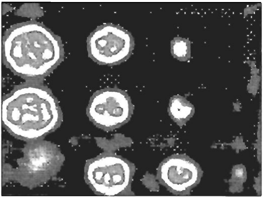

Figure 2. Pitch-Catch C-Scan of an impact damage test panel

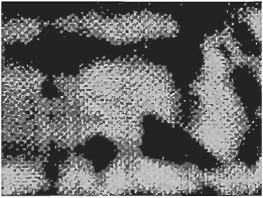

Figure 4. A scan of a panel analysed to highlight the honeycomb core.

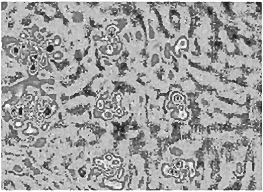

Figure 3. Same scan as shown in Figure 2 above, but this time the data was processed to highlight background scattering effects

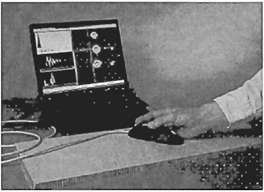

Figure 5. The Bandicoot demonstrator system examining a Nomex cored test panel.

3. THE CSIRO METHOD FOR NDT USING A PITCH-CATCH PROBE

In recent years CSIRO has been researching the use of a common acoustic Pitch-Catch probe for detection of soft impact damage to Nomex cored (paper resin honeycomb), carbon fibre reinforced polymer (CFRP) sandwich panels. This work [2] provided some very useful techniques for analysing the returned waveforms. In particular, analysis methods were developed that can isolate particular features within a test panel such as impact damage, background diffraction effects, and even the core itself. Examples of some relevant images are shown in Figure 2 to Figure 4.

The Bandicoot hand-held scanner

During the course of the study into soft impact damage in Nomex cored CFRP sandwich panels, the idea evolved that a practical outcome of the study could be the development of an improved Pitch-Catch probe, bundled with analysis software developed at CSIRO, and incorporated within its own low cost positioning system. The intended purpose of the design is to produce a simple and cheap NDT system.

The resultant demonstrator consisted of a Pitch-Catch probe housed with a dual optical positioning system, a PCMCIA digitisation card and a notebook PC. The system was given the name Bandicoot after a distinctly Australian mouse-like marsupial.

The hand-held probe

A typical implementation of the Bandicoot design can be seen in Figure 5. The handpiece contains the dual tipped Pitch-Catch sensors and two optical position detection units as well as several user defined contact switches. Also included within the probe are electronics for exciting the transmit sensor, and impedance matching and filters for the receiving channel.

The optical position detection units use light emitting diodes to illuminate a small area of surface that is imaged by a receiver. The two dimensional cross correlation between successive images is calculated giving x and y distances for any movement. As the two distance values are in the coordinate system of the unit, rotational motion cannot be detected and could cause positional errors. The approach taken in the Bandicoot to overcome this problem is to use two optical position units where the correction into the user coordinate system can be calculated knowing the distance between the optical detectors. All positional information is communicated back to a notebook PC via a standard USB port.

The base of the probe has 4 Teflon slides. These are distributed outside the area of the Pitch-Catch NDT sensors and the optical detectors so that the entire unit is held level with the test piece.

Micro switches are also set into the base of the probe to detect lift-off. This is necessary because if the probe is lifted off the panel the reference coordinate system is lost. A number of strategies are incorporated into the software to handle this contingency. The contact detection sensors are situated at the edge of the base in order to allow maximum sensitivity to lift-off.

4. EXCITATION IN TYPICAL COMMERCIAL PITCH-CATCH SYSTEMS

In most existing commercial instruments the user selects the operating points by looking for the parameters that give the greatest difference between good and bad sections of panel. This is one of the major contributory factors to the perceived unreliability of the method. Common pitfalls are:

¥ Selection of the wrong mode (eg. impulse, swept, other).

¥ Selection of the wrong frequency or frequency range.

¥ Selection of the optimal display mode. Data from the returned signal can often be displayed in a number of ways.

¥ Interpretation of the display.

Only some of these parameters will be controlled by the user and their uses are dealt with in the instructions accompanying the system. Even so, experience is required to implement them to the best advantage.

The Bandicoot excitation strategy

The Bandicoot system uses a somewhat unconventional excitation signal. Generally the excitation is quite broadband . In fact versions have been built where the excitation is a step function. However the optimum excitation, being a compromise between narrow and broadband excitation methods, is a burst of only two or three cycles of a sine wave.

A narrow band excitation gives a better detection in principle because most defects in sandwich panels have natural frequencies, determined by their size and type. In the past the reasoning behind the use of Pitch-Catch probes has been based on the idea that propagating Lamb waves are excited in the panel and detected as they pass the receive tip. Where there is a defect, the mechanical impedance of the panel is changed yielding both a delay, ie a phase shift, and an amplitude change between good and defective regions.

A lumped element model of a defect has been found to be most useful. The propagation velocity of flexural waves in sandwich panels are generally in the range 400 to 600 $m.s^{-1}$ and is non-dispersive [3]. Over much of the frequency range used for these probes this gives wavelengths larger than the defects, making propagation models problematic due to the small ratio of defect size to wavelength and the small tip separation.

If more energy is supplied at or around the frequency where the panel best responds, then there is a much better probability of detection and a more accurate estimate of defect boundaries. Where this frequency is known this is obviously a better choice. In fact it is not as difficult as has been traditionally thought to estimate this frequency to within a kHz or so, in some cases, on the basis of other known data [2].

On the other hand, if an appropriate frequency is not known, then a broadband excitation maybe more suitable. The main problem in using broadband excitation is that unwanted resonances, which often have a higher Q than the defect response, are also excited. These may come from the probe or from the test structure. All commercial probes have this problem. If this response falls at or near the defect frequency the functioning of the probe is seriously compromised. If it is sufficiently distant in frequency, band pass filtering will solve the problem but the filter needs to be of a very high Q itself to attenuate these resonances without attenuating the desirable part of the response.

Signal digitisation and processing

On board the Bandicoot probe, the received waveform is passed through a low pass filter for anti-aliasing, and a high pass filter to reduce mechanical, sliding and handling noise. Then it is digitised with a PCMCIA data acquisition card in a notebook PC. The current acquisition card has a maximum sample rate of 300 kHz and a 14-bit A/D converter.

The system is configured by the user in a set-up window, in which the digitised, windowed waveform and the FFT are displayed with the probe in a free running mode. Sampling rate, sample size, trigger delay and windowing function are all selectable but defaults are also included. The user can nominate a result to be the reference result or one may be retrieved from memory.

The frequency spectrum thus obtained is used for the defect detection. The time waveform is not used for the analysis because it is much less robust to handling noise or other interfering signals.

The spectrum usually contains data up to 50 kHz that appears quite complex and without further processing will not give a good result. It is necessary for the user to decide which parts of the spectrum are useful and which parts are artefacts of the equipment and test piece dimensions. On the basis of this knowledge a band of the spectrum can be selected for further analysis.

A selection can be made by viewing the spectrum collected over a good piece of panel. This reveals the frequency structure not introduced by the defect. Knowledge of the likeliest frequency band for defect response allows a range to be chosen where the effects of the defect are maximised compared to other structures, such as those introduced by the probe itself. A small number of built-in ranges are available for some popular sandwich constructions.

5. SCANNING

As mentioned above, the analysis is done in the frequency domain. A band of frequencies may have been selected, either

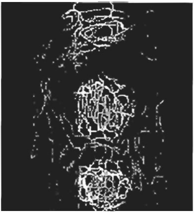

Figure 6. A typical Bandicoot scan

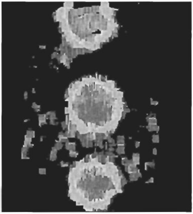

Figure 7. An enhanced image of the scan in Figure 6

by the user during set up or as the default or the complete spectrum can be used. The frequency data is compared to the reference data and a damage index calculated. This number is used to create a colour display of the scan area in the display graticule. An example scan is shown in Figure 6 and Figure 7.

Once a scan has been completed the data can be retrieved and the display recreated. Because the original waveforms have been stored, the software also allows the user to re-analyse them using a different frequency band or re-display the data using different colouring schemes. Areas and traverses of the image may be selected for dimensional measurements and a B Scan option is also available. In this mode the waveforms are displayed continuously in the data window as the mouse is moved over the display graticule.

6. THE NEXT GENERATION OF THE BANDICOOT

Due to the favourable response to the demonstrator, the Bandicoot is to be developed into a fully functional prototype. It is intended that this new design include some of the DSP technology that CSIRO has been at the forefront in developing. The new Bandicoot will contain within itself all electronics and processing required for comprehensive NDT without the need for expensive PCMCIA data acquisition cards. This leaves the notebook PC serving only as a data storage and display device.

Key features of the new design include the following:

¥ 48MHz microprocessor with 64KB of RAM.

¥ Communication and all power supplied by the USB port on a PC.

¥ Pitch-catch probe.

¥ 12-Bit, 400kHz data acquisition.

¥ 8-Bit Arbatry waveform generator.

¥ Dual optical encoders for millimeter accurate movement in X and Y directions, and rotational movement of the probe.

¥ Mechanical lift off detector and optical X-Y position reference (reflective spot) detector.

¥ Assorted LED indicators, Buttons and a Buzzer.

¥ Firmware fully configurable and downloadable from a PC.

By utilising existing CSIRO technology within the Bandicoot, development costs will be kept at a minimum while providing a capable unit that is simple to operate. The design also permits complete reconfiguration via downloadable software to enable the Bandicoot to adapt to new applications.

7. CONCLUSIONS

The Bandicoot is a novel [4] implementation of the acoustic Pitch-Catch probe technique for damage testing of composite panels. It uses new analysis algorithms designed to maximise reliability and increase sensitivity at the same time. The probe is housed in a computer mouse-like structure, which improves the reliability and reproducibility of the results. The probe interfaces with a PC in the conventional manner so a C Scan can be created on the display as the data is collected. Apart from the mouse, the only other hardware requirement is a suitable notebook computer.

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