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Citation: AIP Conf. Proc. 1335, 1743 (2011); doi: 10.1063/1.3592139
View online: http://dx.doi.org/10.1063/1.3592139
View Table of Contents: http://proceedings.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=1335&Issue=1
Published by the American Institute of Physics.

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DEVELOPMENT OF A PORTABLE MECHANICAL HYSTERESIS MEASUREMENT AND IMAGING SYSTEM FOR IMPACT CHARACTERIZATION IN HONEYCOMB SANDWICH STRUCTURES

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ABSTRACT. Honeycomb sandwich materials are commonly used for aero-structures, but because the outer skins are typically thin, 2-10 plys, the structures are susceptible to impact damage. NDI methods such as tap tests, bond testers and TTU ultrasound are successfully deployed to find impact damage, but identifying the type/degree of damage is troublesome. As the type/degree of impact damage guides decisions by the maintenance, repair and overhaul (MRO) community regarding repair, the ability to characterize impacts is of interest. Previous work demonstrated that additional impact characterization may be gleaned from hysteresis loop area, as determined from an out-of-plane load-vs-displacement plot, where this parameter shows a correlation with impact energy. This presentation reports on current work involving the development of a portable hysteresis measurement and imaging system based on an instrumented tapper. Data processing and analysis methods that allow production of the load/displacement data from a single accelerometer are discussed, with additional reporting of tests of software to automatically vary pixel size during scanning to decrease C-scans inspection time.

Keywords: Nondestructive Evaluation, Mechanical Hysteresis, Tap Test, Honeycomb Composite
PACS: 81.70.-g

INTRODUCTION

The continued increases in the use of fiber reinforced composite materials in the construction for aero structures and components is not surprising, given the advantages in weight savings, strength, and fatigue and corrosion resistance the materials offer. However, one of the barriers to widespread replacement of metallic components and structures with fiber reinforced composite materials is the problem of inspection. Composite materials typically do not respond to probing energy, say from ultrasonic tests, in the way monolithic metallic materials do: the layered structure, the high anisotropy, the high attenuation, all these contribute to a decreased characterization capability. This is true for the characterization of virgin materials and in the detection and characterization of service-induced defects and damage. The equipment and procedures developed from years of inspections on metallic structures and components are often inappropriate for composite materials.

With regard to composite honeycomb sandwich constructions, the inspection most often deployed is the tap test [1]. The test is simple, inexpensive, and relatively sensitive to
damage, but suffers from an inability to differentiate the various types of damage, such as crushed or buckled cores, skin/core disbonds or inter-ply skin delaminations. In the airline maintenance community, knowledge of the type of damage present has an impact on repair operations, with crushed/buckled (but still bonded) cores treated as a cosmetic repair, whereas disbonds and delaminations require more extensive (and expensive) repairs. The tap test is often used as a survey method employed to locate anomalies, where another method is then used to characterize the suspect region. However, these other methods, often a bond tester or UT test, are often also marginal in differentiating certain types of defects, such as skin-to-core disbonds and crushed cores. Here we report on current research activities focused on increasing the utility of the tap test, transitioning it from a survey test to increased use for characterization of damage, including the development of electrical/mechanical hardware and software data collection and image generation.

BACKGROUND

In previous work [2], we reported on a novel mechanical hysteresis measurement where the area enclosed in a load-displacement plot, Fig. 1, is correlated to the level of damage in honeycomb composite materials. The physical meaning of the area enclosed by the loop is absorbed energy. More specifically, it is the energy absorbed by the structure due to internal frictional forces. When a crack or buckle develops in a honeycomb core, the number of surfaces where frictional loss can occur increases. In the case of a crack in fiber reinforced composites, the level of frictional loss should increase dramatically due to fibers intertwining with each other when compressed and then having to untangle as the load is reduced and the structure returns to its original shape.

FIGURE 1. Load-vs-Displacement loops for various impacts on honeycomb composite panel. Note decrease in slope of loops and increased loop area with increasing impact energy.
As previously described in [2], the heart of a tap test-based mechanical hysteresis measurement is the instrumented tap probe, an accelerometer with hard metallic tup for tapping the part/sample surface. From just the acceleration data, both load (tapper mass x acceleration) and displacement (the double integration of acceleration with time) can be deduced. The double integration produced two constants of integration, the tapper initial velocity (the velocity at impact) and displacement, both of which must be determined. If was found that when tapping the part surface manually, the initial velocity varied considerably, so processing of the data involved adjusting the initial velocity for each tap to produce a uniform displacement, a time consuming process. However, the results, shown in images of enclosed loop area from a GFRP sample in Fig. 2, demonstrated increased contrast and lower noise when compared to a standard tap test image of contact time (or Tau).

CURRENT WORK – HYSTERESIS MEASUREMENT

With the increased imaging quality provided by the use of the enclose loop area parameter, decreasing the time required to produce images is essential. The major barriers are the data collection (acceleration waveform collection for each tap), the adjustment to correct for variability in the tap test initial velocity and the calculation of loop area (which is essentially a triple integration process overall, when considered with the displacement calculation). In the previous work, the tap waveforms were collected with a DSO and saved to a pc for processing. The DSO is a laboratory instrument, with sampling rates much higher than needed and not particularly suited for a field environment. To enable the creation of a low cost portable system, a Parallax Propeller [3] microprocessor (~$15) and a Maxim [4] Max154B A/D (~$25) were integrated on a custom printed circuit board, demonstrating a sampling rate of ~400K samples per second, which is adequate for typical acceleration waveforms. The hardware is shown in Fig. 3.

FIGURE 2. Contact Time, left, and Loop Area, center, images of GFRP Honeycomb Panel. Panel shown, right, with impact locations.
In other work [5], a motorized tapper was developed to enable increased speed in tap test imaging, capable of tapping in the range of 15-40 taps per second, Fig. 4a. This mechanized tapper also demonstrated much more uniform taps, particularly with regard to initial velocity, and so essentially eliminated the fitting needed in the double integration process. Comparison of typical hand tap waveforms (accelerometer output shown on DSO with persistence) to mechanized tapper waveforms is shown in Fig. 4b.

The Parallax Propeller provides control of the mechanized tapper motor controller, the detection and capture of tapper waveforms, and the calculation of hysteresis loops, finally outputting loop area results from each tap to software on a pc for image generation. The Propeller also triggers a position encoding transmitter, based on the Mimio components as described in [3], which used sonic triangulation for position tracking, with a precision of ±0.020”, more than adequate for hand scanning.

CURRENT WORK – SCAN IMAGING SOFTWARE

We have previously described a generic software platform [6], configured for simple integration to hand-held instrumentation (such as flaw detectors, bondtesters, EC instruments, etc) and capable of producing hand scanned images with minimal training requirements and cost. This software platform, GenScan, is the basis for the imaging software used in the current work. As previously described, the salient feature of the software is the ability to change the image/scan pixel size during a scan. In this way, after mapping out the scan area with larger pixels, if suspect areas are found, the operator may rescan only those suspect areas with finer and finer pixels so to map the true size and geometry of any flaws found. High spatial resolution is therefore only used where it is needed, over flaws.

Testing of the GenScan software platform has demonstrated a significant speed increase over standard manual scans where small pixels are used throughout a scan, with virtually no loss of flaw detection or sizing capability. To further increase scan speed, a feature that automatically changes the pixel size in response to flaw signals is being developed and tested. The concept of automatically changing the pixel size is straight forward, as the flaw signal is already being used to change pixel color during a
scan. When operating the system in automatic mode, the operator moves the mechanized tapper over the sample in any direction or path they choose. When flaws are encountered, the visual feedback of decreasing pixel size and changing pixel color signal the operator to slow down, and rescan the area with the smaller pixels. It has a very “natural” feel. The difficulties appear because of noise. In cases where a flaw has been encountered and pixel size is decreased, a sudden increase in the flaw signal due to noise, appearing like the signal from a unflawed region, will suddenly increase the pixel size, overwriting a region of smaller pixels. In cases like this, flaw signatures can be lost. Various schemes have been tested that minimize the problem, such as running averages to smoothly transition between pixel sizes, or changing the pixel transparency (the 4th byte in a bitmap pixel datum, also described in [6]). A typical scan image, shown after approximately 30 seconds of scanning over a 12” square sample, is shown in Fig. 5.

FUTURE WORK

As currently programmed, the Parallax Propeller is capable of approximately 5 taps per second throughput. The bottleneck is the double integration process and the loop area calculation. As the Propeller has eight internal processors, independently programmable but tied to a master clock, it may be possible to perform the individual integrations and loop area calculations in separate processors, but staggered in time because each result needs to be carried forward in the next processing step. If this is not possible, an analog to the load-displacement loop area will be considered.
The tap response can be modeled as a simple harmonic oscillator, where the tap response is a simple half cycle sine wave. When damage is present, as seen in the hysteresis data, the perfect half cycle sine wave is distorted, so the forward and return paths do not overlap, causing a loop. The hysteresis loop area is then just a measure of this distortion. A simple analog could be constructed where the peak amplitude and period of the acceleration data is used to generate a “reference” sine wave, the sine wave that would result from the response of a “perfect” harmonic oscillator. This reference is then simply compared to the raw data, where we sum the absolute difference between the two waveforms. Example results are presented, where we show the raw data, reference sine waves and absolute difference for a non damaged sample and a damaged sample in Figs. 6 and 7, respectively. Note that both examples deviate from the reference sine wave, as even undamaged materials deviate from a “perfect” simple harmonic oscillators response. Figure 8 presents the comparison of the standard force-displacement (via double integration) method and the reference sine method, where the responses are quite similar.

Test of the sine reference method are in progress, and should save considerable processor time, allowing significantly higher tap data throughput rates, with estimates in the range of 30 taps/second. This would allow higher speed hand scanning, particularly where defects are found and pixel sizes are smaller (when using the automatic pixel size feature of the scan software).
FIGURE 6. Raw acceleration, reference sine wave using raw data period and peak amplitude, and absolute difference for an undamaged honeycomb composite sample.

FIGURE 7. Raw acceleration, reference sine wave using raw data period and peak amplitude, and absolute difference for an impacted honeycomb composite sample.
FIGURE 8. Comparison of impact damage response using the sine wave reference and double integration (load-vs-displacement) methods.

ACKNOWLEDGEMENTS

This material is based on work supported by the Federal Aviation Administration under Contract #DTFACT-09-C-00004 at Iowa State University’s Center for NDE.

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