ELECTRONIC TAP HAMMER FOR COMPOSITE DAMAGE ASSESSMENT

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ABSTRACT

The percentage of composite materials used on new aircraft continues to rise, creating a greater need for NDI methods that can be used on_aircraft and are effective in identifying degradation and damage in composite structures. A particular type of degradation__ delamination due to impact__can produce significant strength or stiffness reduction without being visible to the naked eye. Methods such as pulse echo ultrasonics, shearography, and thermography are being applied to this problem, but are costly to implement. The traditional coin tap or tap hammer method, is low cost, but is inherently subjective, and operator dependent. Boeing has developed a low cost instrumented tap hammer that provides a quantitative measure of the hammer/composite impulse time that can be correlated to delaminations in the structure. The instrumented tap hammer supplements the tonal discrimination of the operator with a numeric readout that can readily be related to local part quality. The effect of background noise and operator differences on the inspection results can be eliminated. An increased sensitivity is, also shown over the audible tap test method. This paper describes the theoretical basis for the impulse measurement, the (patent pending) tap hammer design, test methods, and test results which validate the device.

KEY WORDS: Tap Testing, Composite, Delamination, Non_Destructive Evaluation

1. INTRODUCTION

Boeing has been investigating low cost NDT technology for use with on_aircraft composite evaluation. One goal has been to develop an inexpensive instrumented non_destructive bond tester that can be used as an alternative to coin tap inspection.

There is currently a need in both the commercial and military aircraft industries for simple, low cost non_destructive test (NDT) methods for detecting and measuring flaws and damage in composite structures and repair configurations. State_of_the_art NDT methods for composites (1) are not always available, because they are expensive and require highly trained operators. A simple technique that has been used effectively for many years is the coin_tap (or tap hammer) method. It is used to inspect composite laminates, sandwich structures, and bonded joints (2,3). Though it is cheap and simple, the coin_tap method has several drawbacks: It is dependent upon the inspector's hearing and interpretation, the results are subject to interference from workplace noise, and this technique is unable to provide quantitative data. Various approaches have been used to overcome these drawbacks. However, the various approaches continue to be relatively expensive, and are of limited practical use for on_aircraft inspection. Boeing has taken a unique approach to coin_tap inspection that is simple, practical, and low cost. With this technique, the hand_held hammer is retained as the basic means of obtaining tap data. By instrumenting a traditional tap hammer with a force transducer and associated electronics, quantitative, objective data can be obtained simply and cheaply.

The coin_tap method works because of the difference in the sound produced when a "good" versus "bad" region is tapped. A "good" region tends to "ring," while a "bad" region will sound "dead." The sound difference is due to the difference in the nature of the tap impact. The mechanics of the tap testing method have been studied in detail by Cawley and Adams (4_6). Theoretical and experimental results from their work demonstrate the viability of utilizing changes in features of the force_time curve of the impact as an indication of local "goodness." Damage, such as a disbond, results in a local decrease in the stiffness of the structure, which changes the force_time curve caused by the tap near the flaw. The amplitude, duration, and frequency response of the impact curve are all affected by the local stiffness, and, under various conditions, can be flagged as indicators of defects and damage.

The impact pulse shape was examined in some preliminary experiments at Boeing using a tap hammer with an accelerometer mounted on the head. The accelerometer was connected to an oscilloscope, which displayed its response to each tap. A surprising result was that the impact width is relatively insensitive to the magnitude of the hammer hit, but very sensitive to the local stiffness. 'Mis finding can eliminate the need for a controlled "tapper" (such as the one described in (7)) that maintains a constant pulse amplitude in order to obtain "good" data. Impact pulse duration can correlate with flaw extent in both laminates and sandwich structures, even over the range of tap amplitudes common to a traditional tap test. Human control of the magnitude of the taps is generally sufficient, so the hand_held tap hammer does not have to be abandoned for a more precise (and more expensive) electro-mechanical "tapper." Experimental data, described in Section 3, illustrates the precision of the hand_held approach.

2. DESCRIPTION

A prototype instrumented tap hammer, christened the Rapid Damage Detection Device (RD3), has been designed, built and tested by the Boeing Commercial Airplane Group for use on composite sandwich structure. A second, identical, prototype has been built and tested for use by the Boeing Defense & Space Group, and is expected to be used primarily on composite laminates. Boeing has applied for a patent on this device which appears to be an effective, low cost NDI instrument.

The RD3 consists of a light weight hammer containing an accelerometer, connected by cable through the handle to a hand_held module containing digital logic components and a liquid crystal digital display. A photograph of the RD3 is shown in Figure 1. For the sake of completeness, the user_interface features of the RD3 are listed. They include:

_ Hand held, low cost inspection system.
_ Low weight detection hammer.
_ Large .35 inch display of digital values.
_ Automatic display reset.
_ Scope monitor jack for hammer signal evaluation.
_ 16 hours of continuous operation.
_ Powered by high output chargeable Nicad batteries.
_ Battery recharge external jack.
_ Low battery LED.
_ Durable impact resistant case.

The accelerometer in the head of the hammer translates the force_time pulse at the hammer head due to each tap into a voltage pulse (Figure 2.). A Programmable Array Logic Integrated Circuit (PAL IC) receives the signal, and measures the pulse amplitude. If the amplitude is above a minimum set point (1.5 V) , the PAL IC takes a measurement of the signal width at a pre_set level (4.8 V). The pulse width of the signal is computed by the PAL IC and displayed as a number on the LCD (Iusec = I count). The display resets and shows a new value after each hammer tap. If the minimum set point is not reached (i.e. the tap is too light), a zero (0) is displayed.

As discussed above, the width of the force_time pulse correlates to the mechanical impedance of the local structure being tapped. A delamination in a composite skin, or a disbond between the skin and the core of a sandwich panel, will tend to reduce the local stiffness, and produce a wider force_time pulse (Figure 3). Potting in the core of a sandwich panel will increase the local stiffness, and produce a narrower pulse than nominal. Therefore, deviation from nominal width indicates a deviation from nominal structure. The amplitude of the pulse does not affect the width as one would expect. Within a relatively broad range of impacts, the pulse width remains quite constant. Different operators tapping at various levels, produce similar impact widths, with similar spreads. Ply drops will reduce the local stiffness, and will increase the average pulse width and number displayed. Therefore, knowledge of the design of the skin is essential to identifying true flaws.

3. EXPERIMENTAL

3.1 Step Wedge Tests A series of non_destructive tests was completed using the first prototype RD3 on a special sandwich step wedge. The step wedge has fiberglass/epoxy skins I to 7 plies thick bonded to I in. Nomex honeycomb core. A portion of each skin is disbanded from the core, representing a common type of flaw in sandwich panels.
The RD3 was tested on the step wedge by having three separate operators take ten taps each on the "good" and disbanded areas of each step. Figure 4 is a graph of the averaged

results. There is a significant change in the measured pulse widths for each of the facesheet thickness'. 'Mis change is traditionally observed as a change in the audible tone of the tap. However, a 10% difference in pulse width is easily discerned with the RD3, which is more sensitive at an operator's hearing (Though individual tonal discrimination varies, a change of approximately 25% in the pulse width is necessary to be discerned audibly.).

As the face sheet thickness increases, the change in pulse width caused by a delamination or disbond decreases. Knowledge of the structure being inspected is also important__as it is with traditional coin tap__because of stiffness changes of the skin near rib/spar attach locations.

3.2 Comparison Tests The RD3 was compared with another bond tester on the market that makes use of the impulse created by a tap. This instrument contains a solenoid_driven impact head that produces a controlled amplitude impact. The device has a variety of excellent features, but is significantly more costly. It contains an accelerometer and accompanying circuitry that measures the time from when the pulse goes through _ certain threshold, until it reaches it's peak (see Figures 2 and 3).

When tested on the sandwich step wedge, the solenoid_driven tapper produced similar results to the RD3, as Figure 5 illustrates. The RD3 actually showed slightly greater relative signal change (representing greater sensitivity) at 4, 6, and 7 plies. It did not show as great a signal change as the solenoid tapper did at 2 plies, but sensitivity is not an issue here because the signal difference between bonded and disbanded is so large. In terms of actual data, the RD3 compares favorably with the much more complex and costly device.

3.3 Disbond Extent Test A damaged 747 Kreuger Flap (Figure 6) was chosen to determine how effective the RD3 is at determining the location and extent of core_to_skin disbonds. In a blind test using the RD3, an operator quickly found three disbonds near one end of the flap. By observing the numbers displayed by the RD3 after each tap, the operator marked out the estimated extent of each disbond (Figure 7.). All three disbond appeared to be about 4 to 6 cm in diameter. To determine the influence of different operators on damage estimation, the test was repeated in the same relative locations by two more operators. In each case, the marking produced by the previous operators was erased before the test. None of the operators who were part of the testing were technicians experienced with tap inspection. They were simply shown how the R.D3 functions and told the general location of the flaws they were to "measure." They were instructed to mark the edge of the flaws based upon a reduction of the pulse width of 5_10% (at the digital display) relative to the "good" regions.

An automated TTU (through_transmission ultrasonic) scan was completed for the flap (Figure 8.). A comparison of the tap results between operators was made by measuring the area of the flaw indications marked by each operator using RD3. The same was done on the TTU C_ scan image, with the flaw boundaries selected at a 6 dB ultrasonic signal amplitude loss relative to the "good" regions. Table I shows the results obtained by the three operators and by TTU. Overall, operator A marked slightly larger areas than operator B, who marked slightly higher areas than operator C. However, with the exception of A_2, the tap tests results are all within 1.3 cm2 to the TTU area prediction. This is a reasonable difference, but it is expected that even this difference can be reduced through a small amount of practice.

TABLE 1. Comparison of Predicted Disbond Areas

RD3 Operator	Predicted Disbond Area (cm2)		
	Disbond 1	Disbond 2	Disbond 3
A B C	8.6 8.4 6.5	9.7 8.0 7.7	7.5 6.2 6.2
TTU Result	7.4	6.7	6.8

The results demonstrate that tap testing with the RD3 can be accomplished using only the indicated impact pulse width as a measure of "goodness". While the RD3 can be used like the traditional tap hammer to locate flaws, it requires no special training to operate. In the tests described above, the flaws were sized quickly and easily by inexperienced inspectors who have not yet developed "trained ears." An experienced tap tester would be able to use both the audible and quantitative signal provided by each tap to determine the quality of a structure.

4. CONCLUSIONS

The RD3 addresses the genuine need for a low cost instrumented NDT method for composite commercial and military aircraft. The results of testing demonstrate the benefit of a quantitative indication of the local stiffness (as measured by the impact pulse width). The use of the RD3 provides a clear improvement over the traditional coin tap method, by reducing its subjectivity, increasing its sensitivity, and quantifying the actual impact response. There are limitations as to what thickness skin can be effectively inspected, however. As the skin thickness increases, the difference between the response of "good" and disbanded skin will get smaller (see Figure 4). The effective range for the RD3 was 1_7 plies on the fiberglass/epoxy face sheet of the sandwich panels tested. The range will depend upon the material and type of structure, as well as the defect type, size, and depth. For example, de-laminations in 6 mm thick graphite/epoxy composite laminates due to impact have been discerned with the RD3.

The RD3 demonstrates similar results to a much higher cost instrumented tap hammer with additional features that is currently on the market. With its low cost, clear benefit, and ease of use, the RD3 should find a niche in the composite NDT field. Because improvements or modifications may be in order, time for customer demonstrations and feedback will be allowed before finalizing the design features of this instrument. Potential improvements may include a means for data storage and a visual or audio alarm to allow quick determination of local stiffness changes. Because most significant advantages of the RD3 over other methods are low cost and ease of use, the merits of possible improvements will be weighed against the drawbacks of increased cost and complexity.

5. REFERENCES

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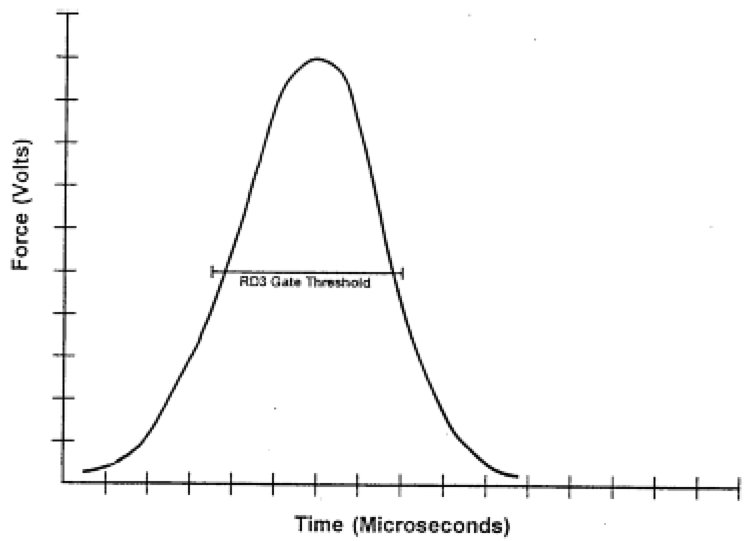

Figure 2. Typical RD^3 force-time pulse over “good” region

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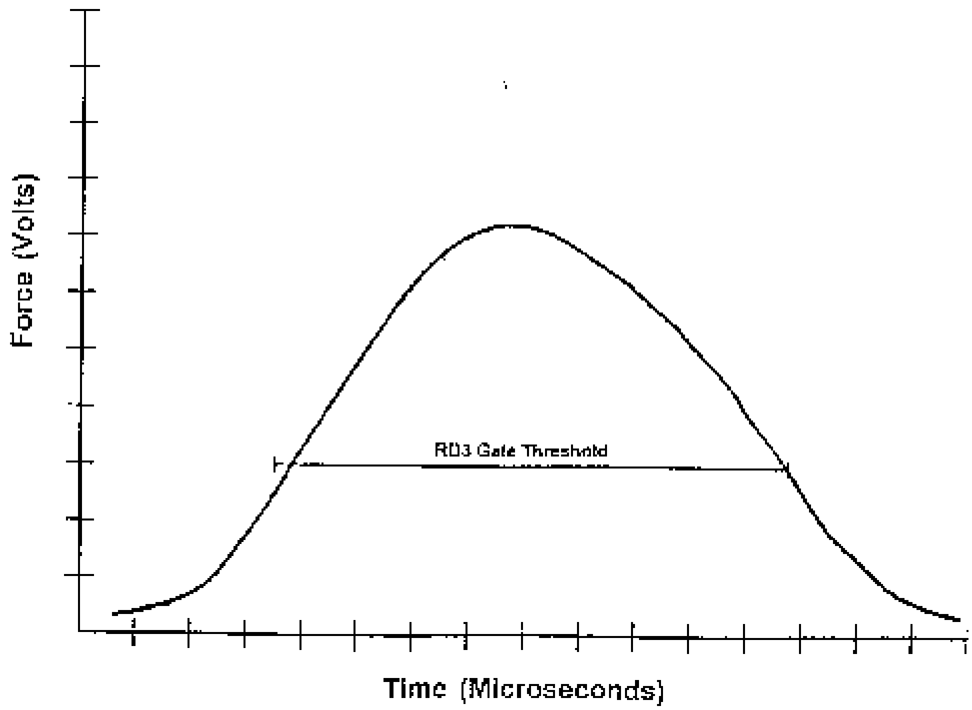

Figure 3. Typical RD[3] force-time pulse over “poor” or disbonder region.

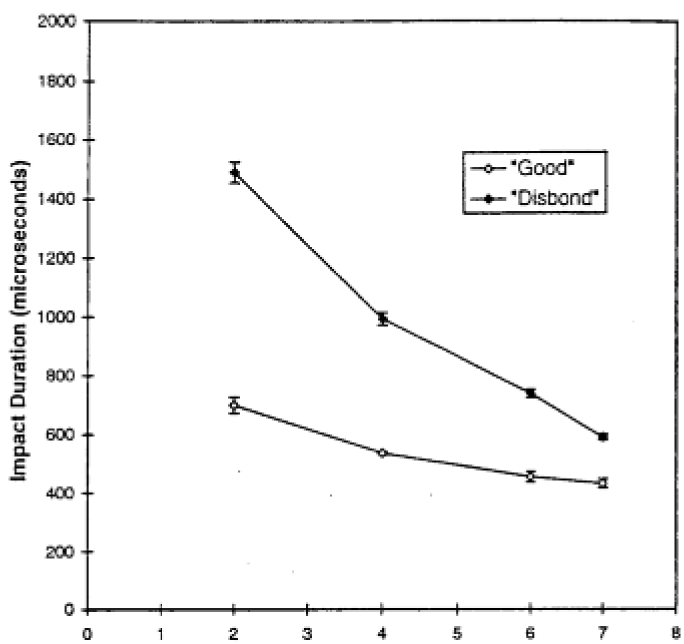

Figure 4. RD^3 results on fiberglass/epoxy skin. Nomex honeycomb core test panel.
A single operator made ten taps per region. Error bars show +/- one standard deviation.

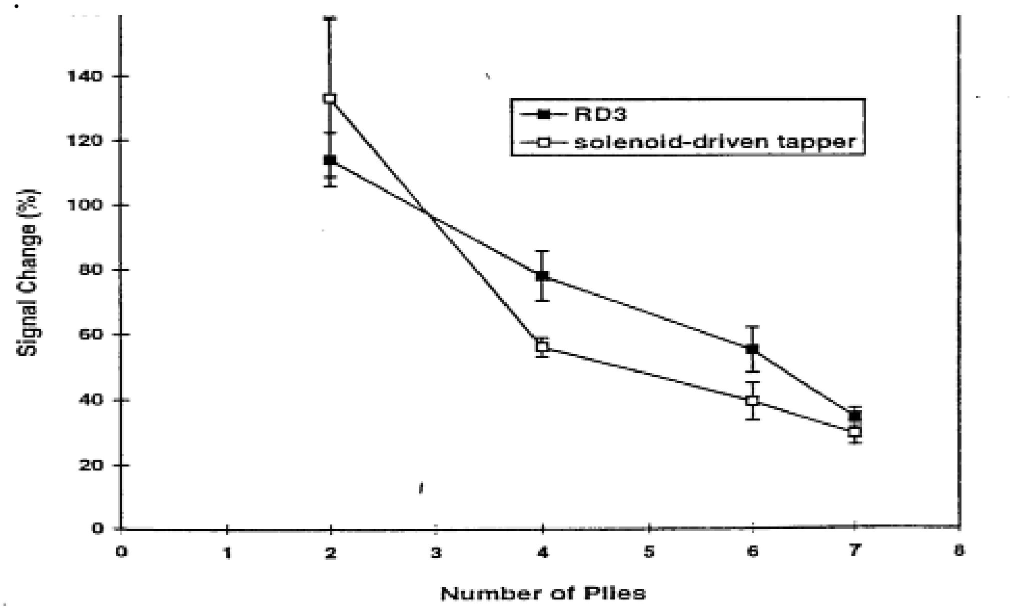

Figure 5. Measured signal change between bonded and disbonded regions of tet panel.
Each point is an average of three blind tests using different operators. Error bars show +/- one standard deviation.