Characterization of damages in materials by computer-aided tap testing

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Abstract. The tap test is an easy and effective way of characterization of flaws and damages in different materials (especially honeycomb sandwich composites). When the tapping is carried out systematically to cover an area, the measured impact duration can be used for generating a “scan image” of the tapped area. Such an instrumented tap test and imaging system can be used for the detection of flaws and damages, for the evaluation of repaired areas and for the verification of normal reinforced substructures. In this study, the images of intact and damaged aluminum honeycomb sandwich composite, pine board and poplar board samples were obtained by using Computer Aided Tap Tester (CATT) system in the electric and magnetic field and also without any field. As a result of the tests made, it has been figured out that the tests made in the electric field and the magnetic field increased the quality of the images for damages. Also, it has been found out that the CATT system is quite successful in detecting damage of honeycomb sandwich composite materials.

1. Introduction
Composite materials are used in many applications ranging from aerospace vehicles to consumer products in our daily life. The composite structures can be damaged from many causes. For instance, these composite materials can be damaged during the production process and during the in-service life of them [1]. For many composite structures, the most significant damages occur by mechanical impacts. Impact damage can be created by dropped tools, hailstone and bird strikes etc. Composite materials have a variety of damage types such as delamination, micro-cracking, and porosity. Therefore, important materials such as composite structures used in aircraft’s bodies need to be able to quickly pass through non-destructive inspection process. Nowadays, the development of health monitoring solutions has gained considerable attention [2-4].

The hearing-based tap test is one of the most practiced inspection technique on composites. This method only requires a coin and a good sense of hearing. When the surface of a material is damaged with the coin, it creates a sound which is related with the local stiffness. If a tap occurs over a damaged zone, one can hear a sound have a “dead” tone. While a tap occurs over an undamaged zone, one can hear a sound have a higher tone[5]. However, the hearing-based tap test depends on the human ear. There are three developments of instrumented tap test which eliminated the human factor of reliance on operator hearing. One of this system, which eliminates the dependence of human ear is developed by Iowa State University and is called the Computer Aided Tap Tester (CATT).

The computer aided tap test is a method, which makes use of an accelerometer and electric circuit to capture the contact time of the tap. The amplitude of the acceleration depends on the force used...
along the tapping. However, the contact time is independent of this force. Based on a simple grounded spring harmonic oscillation model, the contact time $\tau$ is related to the local stiffness (spring constant) $k$ by the simple equation-1[5]:

$$k = m \left( \frac{\pi}{\tau} \right)^2$$  \hspace{1cm} (1)

Where $k$, $m$ and $\tau$ are stiffness, mass of the tapper and contact time respectively. The stiffness at different regions tested part can then be plotted as a stiffness image of the composite structure. Therefore, the CATT system can quickly figure out the damaged regions in the materials. In the related literature there is not any study, which has figured out the effect of electric and magnetic fields on images of damage obtained by CATT system. Therefore, this research was done for investigating the effect of electric and magnetic fields on the characterization of damage in materials by Computer Aided Tap Tester (CATT).

2. Experimental

2.1. Materials and Equipment

In this research a Computer aided tap tester (CATTV5_3-ASI, USA) system, an aluminum honeycomb sandwich panel-15cm x 15 cm x 1 cm - (Altigen, Turkey), a poplar board (13.5 cm x 13.5 cm x 2.4 cm) and a pine board (15 cm x 15 cm x 2.3cm) were used. Also, in the experiments strip and neodymium magnets, 1.5 V DC power supply, multimeter, rheostat, aluminum foil, transparent 0.5 cm partitioned acetate, tape, ruler with mm section and conductive cable were used.

Sandwich materials used in the research are produced by Altigen Space Aviation, Ship Construction Industry Trade Ltd. Co. The materials used in the research and the experimental setups are given in Figure1.

![Figure1. Equipments and experimental set up used in the research: a-The materials used in the research, b-CATT system and electric field circuit, c- Strip and neodymium magnets, d- Tape and 0.5 cm partitioned acetate, e- Tap duration time scale.](image)

First of all, the contour images of intact samples obtained with the CATT system and then all materials samples were damaged. The damages of the samples used in this study were formed by drill machine and a hammer.

2.2. Materials Characterization with Computer Aided Tap Tester (CATT)

In this research, the contour images of intact aluminum honeycomb sandwich, poplar board and pine board were obtained by using Computer Aided Tap Tester (CATT) system in the electrical and
magnetic fields and also without any field. The contour images were obtained using tap duration times (contact time) and stiffness values of the samples.

After opening the ASI CATTV5_3 program installed on the Acer one 10 model computer, a scanning window equivalent to the size of the sample examined is opened. When this window is opened, the unit of inch, cm or mm and the step of progression can be selected at the desired accuracy (eg 0.5; 1; 2 or 2.5 steps if cm is selected). For each tapping operation, the contact time of accelerometer appears in different colours in microseconds (μs) on the screen of the computer. The obtained contact time values can be transformed into the local stiffness contour image with CATTV5_3 program in accordance with the equation of 1, and CATTV5_3 can also give 3D images of these contact times and stiffness values using the data.

3. Findings
The normal contour images obtained from the contact time and stiffness values of all the materials used in the research were obtained by tapping tests without any field and in presence of electric field and magnetic field. These images are given in Figures 2-7.
Figure 2. The images of intact and damaged aluminum honeycomb sandwich panel obtained by using the contact time: a) Without any field, b) With electric field, c) With magnetic field.
Figure 3. The images of intact and damaged aluminum honeycomb sandwich panel obtained by using the stiffness values: a) Without any field, b) With electric field, c) With magnetic field.

Figure 4. Images of intact and damaged pine board obtained by using the contact time: a) Without any field, b) With electric field, c) With magnetic field.
Figure 5. Images of intact and damaged pine board obtained by using the stiffness values: a) Without any field, b) With electric field, c) With magnetic field.
Figure 6. Images of intact and damaged poplar board obtained by using the contact time: a) Without any field, b) With electric field, c) With magnetic field.
Figure 7. Images of intact and damaged poplar board obtained by using the stiffness values: a) Without any field, b) With electric field, c) With magnetic field.

The images obtained from the stiffness values in Figure 5, as well as the contact time images obtained for the pine board were not only precisely revealed all of the damage. Images showing the local stiffness map of the material also revealed useful information about the general structure of the material as well. It can be seen that the damages that are formed in the materials can be detected from the contact time and stiffness values and the electric and magnetic field presence affects the obtained image quality as well.

The images obtained from the stiffness values in Figure 7, as well as the contact time images obtained for the poplar board were precisely revealed all of the damage. Especially, the images showing the local stiffness map of the material revealed the damage very well. The images give very important information related the damages on the surface and subsurface of the material and the structure of the material.

4. Results and Discussions

The product range in the manufacturing sector; quality, technical safety, durability and suitability for the purpose of use, as well as the unconditional assurance of the product is formed with the developing technology. As the aim is to provide continuous and high quality in production, the importance of non-destructive inspection methods in quality control applications is increasing. As described before, there are many non-destructive test methods.
The physics of the coin-tap method have been very well investigated and explained by [6]. The Wichitec RD3 made of Wichitech Industries, the Computer-Aided Tap Testing (CATT) made of Advanced Structural Imaging Inc. [7] and the Woodpecker made of Mitsui Technologies are examples of the automated tap testing systems that eliminate the reliance the human hear. It was figured out that the load versus displacement curve of an un-damaged composite was linear and there was not any hysteresis. Also, the average slope of the load-displacement stiffness of an undamaged composite honeycomb panel was higher than the damaged composite sample. It was also found out that the area enclosed by the hysteresis loop gave a good correlation with the impact energy which caused the damage on the composite sample [8]. On the other hand, Gryzagoridis and Findeis [9], had used Digital Shearography and Tap Testing Methods to figure out the damage in composite materials of both the monolithic and sandwich types. They used the Digital Shearography to benchmark the results obtained with the Tap Testing Method. They had performed the tap testing using the Mitsui Woodpecker WP-632AM which is a hand held automated impact instrument that displayed the defects’ positional data on a PC in real time. They had figured out that the results obtained with Digital Shearography on the same test sample had proven the results obtained by the Tap Testing Method.

In this research, the Computer Aided Tap Tester (CATT) is used to figure out the damage by without using any field and using electric and magnetic fields. As it can be seen from the related literature, there are not any researches that have investigated the effect of the electric and magnetic fields to reveal the damage of materials. Therefore, this research is a unique research. Because that this is the first time that the effect of the electric and magnetic fields on the damage characterization and on tap test images is studied.

Within the scope of the research, the damage generated in various materials was tried to be determined with contour images obtained from the stiffness values and contact times of tapper on the surface of the materials to investigate the electric field and magnetic field effect by CATT system. Thus, the effect of the electric and magnetic fields on the damage have been investigated with a new method, which has never been tried before in the literature.

It can be seen from the Figure 2 and Figure 3 that both the contact time and stiffness values can be used to determine the damage of the material and at the same time the electric and magnetic field presence affects the obtained image quality. A difference in images in the presence of electric and magnetic fields was an expected result. Because the aluminum honeycomb sandwich panel’s core and face sheet is made of aluminum. The main reason underlying the expectation related this difference is that aluminum is a material that has both conductive and paramagnetic properties. For paramagnetic materials, the direction of magnetization is the same as the direction of the external magnetic field. As a result of this, paramagnetic materials are attracted by magnets [10]. Materials such as aluminum can get a different structure if they are transient due to the effects of electric dipoles and magnetic dipoles in the magnetic field. For this reason, it can be said that the images obtained from the tapping test made on the damaged aluminum and intact aluminum materials in the presence of electricity and magnetic field are obtained with better quality.

The contour images obtained by using the contact time and stiffness values of the pine board are shown in Figure 4 and Figure 5. From the data of these figures, it can be seen that the damage in pine board can be clearly revealed from the contact time and stiffness values as seen in aluminum honeycomb sandwich panel materials. Also, at the same time the presence of electric and magnetic fields affect the image quality positively as well. The reason for this is that the stiffness of the pine board is lower than the stiffness of the tapper.

According to the Figure 6 and Figure 7, which obtained for intact and damaged poplar board, it can be concluded that the damage can be sensitively revealed by the CATT system in the presence of the electric and magnetic fields as well as aluminum and pine board samples. According to this result, it can be said that the CATT system is a very successful, practical, easy and inexpensive method for revealing the structures of wooden structures and their damages in particular.

5. Conclusions
Based on the experimental results of this study, which is carried out by the CATT system, the following conclusions can be drawn:

1. The damage in honeycomb sandwich panel materials can be figured out using CATT system without using any field. However, when tapping test was carried out in the presence of electric and magnetic fields, the damages in these materials can be revealed more sensitively.

2. The effect of electric and magnetic fields has been tested for the first time in tap test by using the CATT system.

3. It was found out that the CATT system is very suitable for revealing the damage in honeycomb sandwich composite panels.

In this study, the presence of electrical and magnetic fields was tested to see whether there was any effect on the images obtained by the tapping test in order to determine the damages in various materials. This research is so important by investigating the effect of electric and magnetic fields in damage analysis by tapping test for the first time. The results of the research showed that electrical and magnetic fields have different effects in damage analysis with the tapping test. For this reason similar studies can be repeated with different electric and magnetic fields levels. Damage caused by impact tests with different energies can be analyzed by the CATT system in the presence of different magnitudes of electrical and magnetic fields too.

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