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An Approach and Experimental Technique for Damage Detection of Composite Panels Using PZT Sensor

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Abstract: **At present, the advanced composite materials have gained it acceptance in the aerospace, civil structures and mechanic industries and had increased dramatically from the late eighties to the beginning at this decade. This paper describes an experimental analysis of laminated composite panels made of three different types of fibers reinforced epoxy. The design and dimensions of Al-6061-T6 floor's panels are taken, while the same design and dimensions of these composite panels are used as well. The objective is to compare the mechanical properties, microstructure and thermal plastic analysis of these laminated composites with AL 6061-T6 alloy characterizations. In addition, vibration analysis of composite's panels is also performed using NI-LabVIEW and compared with experimental results of Al 6061-T6 panels.**

Keywords: **Structural health monitoring, Damage identification, PZT sensor, Data Acquisition, Composites, Statistical Analysis.**

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1. INTRODUCTION

Civil, aerospace and mechanical structures are the most expensive national asset of any country. These structures have long service life and are very costly to maintain and replace once they are built. In the past few years, Structural Health Monitoring (SHM) technique has been a growing issue, acknowledged important consideration in outstanding to its extensive applications. SHM is the implementation and procedure of a damage detection to assess, improve and ensure the integrity, safety and reliability of the engineering substructures before it reaches to a critical state. Once these structures life and its substantial usage started, it becomes crucial to monitor and assess their structural integrity. Damage detection existences in these structures can enhance the safety, security elongate the structure service life, and reduce the operational and maintenance costs. Early detection of the damage or structural degradation prior to local failure can prevent a catastrophic collapse of those structures. Typical damage in these infrastructures might be due to the development of cracks, degradation of structural connections, bearing wearing and shearing in rotating machinery, or from excessive external loads such as: strong winds, earthquakes, explosions and vehicle impacts. The most important structures include high-rise buildings, bridges, power utilities, nuclear power plants, and dams, in addition to, aircraft and mechanics applications. The goal of SHM is to improve safety and reliability of infrastructure systems by detecting damage before it reaches to a critical state and allow rapid post-event assessment. Tall buildings materialized in the late nineteenth century and developed a marvel worldwide architectural. Universally, many tall buildings were built especially in Asian countries, such as Japan, Malaysia, Korea and China. Conventionally, the tall buildings developments functions have been as commercial office buildings since rapidly increased or residential, mixed-use, and hotel tower. The construction of tall building will be continued due to their important economic assistances in dense urban land use. "Tall building development involves various complex factors such as economics, technology, municipal rules, and politics, and economics has been the primary governing factor. The new structures type itself would not have been possible however without supporting technologies", (Ali and Moon, 2007).

Recently, extensive research works in civil and aerospace applications have been extended by using fibre-reinforced plastic composite materials. Composite materials are increasingly being used in substructure applications such as reinforcement in structural shapes, various hybrid structures, pre-stressing for new concrete structures, strengthening for existing concrete as well as for bridge decks. These materials contain strong and continuous fibers bound together by a continuous matrix of polymer resin. The development of composite materials has enhanced rapidly because of improvements in process technology and economic benefits. Significant mechanical properties results of composite material has great advantages extending from increased strength and durability features to weight reduction and lower petroleum ingesting if it is compared with conventional and competitive materials. Structural vibration control along with smart materials is gradually used for flexible structures and it attained incredible progress. This is apparently in response to the high demand for safer structures and its lower costs. For rational structural health monitoring applications, the large size of host structures may require innovative sensing technologies and use of appropriate software and hardware systems for data acquisition or reduction. A novel smart sensors and actuators, such as Piezoelectric Ceramic Lead Zirconate Titanate (PZT) transducers identified the method of structural health monitoring technology development and it is widely used for monitoring requests. PZT materials are utilized as a powerful and innovative tool for local damage detection of various structures. LabVIEW software provided a small, simple, and affordable system for making vibration measurements in the lab and field. LabVIEW offers unrivalled integration with thousands of hardware devices, including NI-DAQ. It provides hundreds of built-in libraries for advanced analysis and data visualization as well as analyse data in real time, and create custom reports using the industry standard tool. In general, a typical SHM system includes four major components, (Dong et al., 2010):

1. Structure prototype,
2. A sensor system,
3. A data processing system including: data acquisition, program, and storage, and
4. A health evaluation system: including diagnostic information and organization.

2. LITERATURE REVIEW

Damage detection, damage diagnostics or Structural Health Monitoring (SHM) were defined as determination of the state, integrity or condition of a structure by using the structural measurements and any change as crack, holes, bolt or welded joints which can affect the structure specification (Park and Inman, 2001). Various experimental, numerical and theoretical investigations and studies that reported and revised the damage detection and identification were presented in this literature. These studies included metal, concrete and composite materials in various structures. These scholars used several sensors, methods, devices, programing and software.

In 1880, Jacques and Pierre Curie discovered the piezoelectric effect in the crystals of tourmaline, quartz, topaz, cane sugar, and Rochelle salt, Mascareñas, (2006). Acceleration or pressure as physical parameters can convert into electrical signals via sensors (APC International). Recently, piezoelectric ceramics PZT a powerful tool has emerged for structural health monitoring and it acts as a sensor and an actuator Wang et al., (2014). Piezoelectric ceramic Lead Zirconate Titanate (PZT) transducers are progressively practical for SHM applications. Usually, the PZT as sensors or actuators are bonded on the surface or embedded in the structure and subjected to interrogate the structure at the frequency range. PZT used on the principle of Electro Mechanical Impedance (EMI) as a talented tool for SHM in real time. However, SHM become active monitoring system due to using PZT as sensors and/or actuators which are accessible to utilize SHM of civil, aerospace and mechanic structures (Sun et al., 2010). Annamdas and Soh, (2010) reported the developments in the field of PZT in the past two decades based on SHM. Piezoceramic (PZT) transducer has progressed as an efficient smart material that involved in Electro Mechanical Impedance (EMI). Panigrahi et al., (2010) also used Piezoelectric-ceramic Lead Zirconate Titanate (PZT) patches and bonded on the surface of the structure (a pipe strut) to monitor the damage in the form of a hole. The structure was subjected to an alternating voltage excitation via impedance analyser/LCR meter, and sweeping through a specific frequency range. Based on the signatures of the healthy state structure as the baseline, frequency plots labelled the real part of admittance. So that, any change occurred in the state of the structure was established as a deviation in these signatures to use for SHM and NDE. To quantify the damage, Root Mean Square Deviation (RMSD) as non-parametric quantification was involved. The results improved the proposed technique to determine and detect the damage at the beginning and after expansion. Whereas, Sun et al., (2010) considered smart sensing techniques (materials/sensors) of varies applications like: fibre optic, piezoelectric, magnetostrictive and self-diagnosing fibre reinforced composites. The significant abilities of smart sensors to monitor several physical or chemical parameters were correlated to the health and thus robust examination life of structures was improved. Whereas, Yan and Chen, (2010) reviewed the development's applications of the Electro Mechanical Impedance (EMI) based on SHM. The result presented how this method was very sensitive to incipient the structure's damages, and can indicate the damage when EMI changes. For initial damages in the structures, EMI method exhibited enormous sensitivity. PZT size and excitation frequency range were presented, as well as PZT patch's range sensitivity and exterior action on EMI structural health monitoring technique. Where, Damages detection was adapted in several laboratory sizes' structures to demonstrate the viability of the EMI method. Although, along the length and width directions of the aluminium plates, holes were drilled and experiments were carried out by Yang et al., (2009) to monitor the damage propagation by using the EMI method and PZT transducers grade PIC 151. Comparison was done between the PZT admittance signatures of the original case with each damage case. A semi-analytical EMI model was involved to predict and compare the PZT admittance signatures with experimental signatures. Quantitative analysis of admittance signatures was obtained based on the Root Mean Square Deviation (RMSD) index as a statistical method. The results approved that EMI method was capable to use for monitoring damage propagation. Although, Crider, (2007) studied Lamb wave methods experimentally for SHM to detect damage in four aluminium test's specimens via pitch-catch and pulse-echo techniques. Three piezoelectric transducer (Piezo Ceramics, APC-850) sensors and low frequencies were used for undamaged structures. The results improved that the pitch-catch technique is the best method to detect the crack damage in the constrained geometry due to its ability to reduce the influence of the interference of replicated waves off the boundaries.

Established on a novelty detection method, Mustapha et al., (2007) presented Outlier Analysis (OA) and a Multi-Layer Perceptron (MLP) neural network to detect and localise structural defects. A thin rectangular plate with isotropic behaviour was evaluated experimentally to improve the efficiency of the technique. In both damaged and undamaged conditions and via eight PZT bonded patches, the investigation of the scattering effect of an ultrasonic guided wave on the plate were comprised. From the waveform responses, the true conditions of the plate were demonstrated successfully by the novelty detection method. However, vibration oppression of civil structures was revised by Song et al., (2006). The study included the smart materials such as: piezo ceramics, fiber optic sensors, shape alloys and numerous other materials. PZT was presented as material, type and applications as sensor or actuator in a different civil structures (frame, beam, truss and cable stayed bridge). PZT validated as a various forms: rigid patch, flexible patch, stack, macro fiber composite (MFC) actuator, and PZT friction dampers. In a high strain area or composite structure, PZT patch can be embedded on the surface of structures or embedded into structure like composites. Also, a brief review of Lamb wave's theory was presented by Giurgiutiu, (2005). He explored the capability of embedded Piezoelectric Wafer Active Sensors (PWAS) to excite and detect tuned Lamb. The pulse echo technique using the phased array principle was demonstrated as an effective SHM method for crack detection. The results verified that: via PWAS the Lamb waves can be acceptably created and detected, and signals showed strong enough while reduction was adequately low for echoes to be detected. Although, under both damaged and undamaged conditions for hollow cylinder-like structure, Mustapha et al., (2005) investigated the scattering of an ultrasonic-guided wave to detect incipient damage. In a real time data acquisition, disc shaped piezo ceramic transducers were used to transmit the wave successively and designed a structural health monitoring system. Fast Fourier transform (FFT) on the acquired output signals used frequency domain values which was obtained to lead the statistical analysis established on Mahalanobis squared distances method. However, the impedance method combined with a finite element model by Naidu and Soh, (2004) presented damage growth characterization. Piezoelectric transducer bonded on the structure and detected the damage through the changes occurred in the EM impedance signatures. So that, damage growth was characterized when the changes measured the natural frequency shifts of the structure removed from the EM access signatures. The ability of RMSD values was derived to distinguish the damage growth clearly. The increase in RMSD values which showed the peak shift in the signatures was due to increase in damage. In addition, a lead zirconate titanate (PZT) patch was bonded on surface by Mufti, (2002) to monitor the structure and considered the electro-mechanical admittance signature. The use of PZT as smart sensor did faster development in the fields of structural identification and mechanical SHM. The sensor organization can provide information as effective for monitoring and measurements in four probable levels: damage detection, damage location, damage magnitude severity, and damage prognosis.

Giurgiutiu and Zagrai, (2002) investigated structural identification by using ultrasonic frequency on accurate turbine blade specimens to measure the electro-mechanical (E/M) impedance response of a structure via embedded piezoelectric wafer active sensor. Wide and narrow beams results were compared to identify the effect of width on the frequencies spectrum. HP 4194A Impedance Phase-Gain Analyser was equipped to measure the E/M impedance and admittance spectra of the PZT active sensors. The statistical distributions of the frequencies such as the mean values and standard deviations were obtained. The results approved that the basic piezoelectric wafers had adequate quality with a narrow scattering band in significance frequency. Where, in situ damage detection of composite materials was presented by Kessler et al., (2002) through an experimental and analytical survey. Quasi-isotropic graphite/epoxy rectangular test specimens were clamped on one end with varies damage modes, such as delamination, transverse ply cracks and through-holes. Lamb wave and three piezo ceramic sensors were used. The experimental results observed that no effect for the boundary conditions around the specimen's frame on the Lamb wave which travelled between two piezo ceramic patches. Moreover, the procedure was easy and able to determine the time of a Lamb wave flight between an actuator and sensor. Whereas, Giurgiutiu and Zagrai, (2001) performed the theoretical analysis for particular boundary conditions in order to model the experimental setup of 1-D and 2-D structures. The experiment analysis showed how E/M impedance spectrum accurately identified the natural frequency spectrum of the common members of aircraft plates. HP 4194A Impedance Analyser was used to collect the data via 7mm square and circular PZT active sensor which was placed in the centre of the five square and five circular plate's centre to measure the natural frequencies. With this sufficient number of plates, a statistical data were analysed. The results observed the changes of the spectrum in the presence of local and small crack. Besides, Giurgiutiu and Zagrai, (2000) achieved the numerical analysis and experimental results. PZT active sensors are produced in a thin piezoelectric disk, and the axi-symmetric radial vibrations are considered. For simple beam specimens and on thin aluminium plates, experiments were conducted to illustrate the probable method. The Electro Mechanical Impedance spectrum was recorded and represented accurate mechanical response of a structure. Statistical analysis was also presented. The results showed that the PZT active sensors have stable and repeatable characteristics as received condition.

Based on health monitoring of structure and it status, Yan et al., (2013) provided important technical support. For an experimental monitoring purpose, a three-storey of steel frame model was used in order to test the reliability of the acceleration monitoring model. A shaking table test was chosen to simulate the real acceleration response of the model under earthquake. In order to develop the structural health monitoring system, short development time was improved via using piezoelectric sensors and the graphical programming software was LabVIEW. The results showed the reliability, portability and improvability of technical support to solve applied problems and a good foundation for piezoelectric health monitoring technology. Furthermore, size and selected locations of PZT discs with 8 mm diameter and 1 mm thick were defined by Silva et al., (2011) to present the damage location. A simple support of an aluminum plate with 600 mm side and 2 mm thick was performed as the experimental part of this study. The selected and developed data acquisition and signal generation were also presented. The results detected 1mm damage in damaged plate successfully and repeatedly with great assurance. All damages were positively detected and realized in LabView. Another case study was done by Silva et al., (2010) by using square aluminium plate with 2 m x2 m and 2 mm thick in order to perform SHM via Lamb waves which reflected geometric discontinuities such as damage and material properties. The plate examined was in three boundary conditions ranging from totally supported, simply supported and riveted along the edges. Three transducers were bonded on the upper surface of the aluminium plate to perform the network system. The waveform generator was NI arbitrary, capable of 100MS/s and a NI 60MS/s was used, addition 8 channels with simultaneous acquisition and oscilloscope. The study successfully detected 1 mm damages which were introduced in the plates at different locations. Moreover, for damage growth monitoring and multiple damages detection, the capability of the system was provided. Also, for electrical impedance measurement with new developments and practical applications, impedance analyzers is limited expensive, bulky and heavy. Consequently, Baptista and Filho, (2009) presented an efficient and inexpensive methodology based on the E/M impedance technique. A PZT patch of (20 mm x 20 mm x 0.2 mm) and surface bonded on the aluminum beam with dimensions (600 mm x 25 mm x 4mm) in free ends boundary conditions. A steel screw nut of 4 mm external diameter was bonded to the beam at three positions (50 mm, 200 mm, and 400 mm) from the PZT to simulate the damage in the beam. USB-6211 DAQ device connected to the USB port of a notebook to run the effective system Windows and the LabVIEW package. Based on the Root Mean Squared Deviation (RMSD), the resistance in healthy condition (without the screw nut) compared with the resistances of the three damaged conditions to prove the productivity and accuracy of the new methodology. Moreover, Kirikera et al., (2008) approved that the Structural Neural System (SNS) can minimize the required number of data acquisition channels and predict the location of fatigue damage based on Acoustic Emission (AE) monitoring. Real-time continuous monitoring of a flat coupon cut from a large orthotropic plate of glass fiber woven composite material with 1.25 cm thick and 8.0 cm wide was used. The composite plate has approximately 60% volume fraction of fibers. The composite specimen was loaded on a four-point bending fixture. The damage was monitored by using four piezoelectric sensors in (15 mm x 5 mm x 0.3 mm) wafers. Two channels captured the signals and stored in digital form by a program written in LABVIEW. A simple, practical health monitoring technique was developed to predict the location of damage in real time. Moreover, Mustapha et al., (2007) improved the novelty of detection method using outlier analysis (OA) with successful results, and a fault on the wing holder parts demonstrated in both (time domains and frequency domains). National Instrument NI-PCI 6110 Data Acquisition (DAQ) card was installed in a PC to measure the data. Significant results improved the capability of structural health monitoring technique to determine the damage for complex parts and ageing aircraft structures. With a high dimensional observation data set and based on Mahalanobis squared distance, the undamaged and damaged types were represented successfully. District of the waveform was selected for damage. Finally, as a comparative processing results of impedance spectra, Giurgiutiu and Zagrai, (2005) enhanced that the damage metric can quantify when the damage presence, and due to that the damage index can be assessed. Numerous damage metrics were obtained to compare impedance spectra and to measure the existence of damage such as the Root Mean Square Deviation (RMSD).

3. SCOPE AND OBJECTIVES OF THE WORK

The aim of this research is damage detection and identification to incorporate a robust Structural Health Monitoring (SHM) scheme. This technique is applied on an aluminum alloy and composite materials that emulate three-story structures through an application by using smart materials technology as PZT sensor. This sensor is used to capture natural frequency and power spectrum responses in distinguish structural status. This research scopes and objectives are included:

1. Design and Construction: Design the three-story of aluminum frame to be the innovative structure (prototype) for the four case studies. A definition for the materials, smart sensor and data acquisition with suitable software.
2. Composites Fabrication: Three fibers/ epoxy composites fabricated involved three types of fibers mix individually with epoxy resin as a matrix. Compute the mechanical properties, micro structure and thermo plastic analysis of fabricated composites and to assess the qualification of the new components and compare the results with the Al 6061-T6.
3. Data Acquisition and Feature Extraction to Identify the Damage: Acquire data via SHM technique using PZT sensor and NI LabVIEW Signal Express software. Observation and evaluating the natural frequency distinction as one of the dynamics properties of structures via the specimen's excitation and from the large set of data acquisition.
4. Operational Evaluation: Evaluate the new composite materials through acquire and undergo the feasibility study of the captured real time signals for crack damage detects using a smart system. This research is consist of four material's panels in four cases: undamaged as a 1st case and considered as a reference, in addition to three cracks formed with length as 10mm, 15mm and 20 mm to simulate 2nd, 3rd and 4th cases, respectively.
5. Statistical Pattern Recognition: To evaluate and assess the vibration effects on selected specimens and to provide the significant and effectiveness of the SHM system for damage detection and identification on composite panels. Statistical analysis according to Root Mean Square Deviation (RMSD) index and Frequency Reduction Index (FRI) equations were performed the results to compare the three composites with an Al 6061-T6 panel's results.

4. METHODOLOGY

The flow chart plotted in Fig.1 to illustrate the research's methodology under consideration.

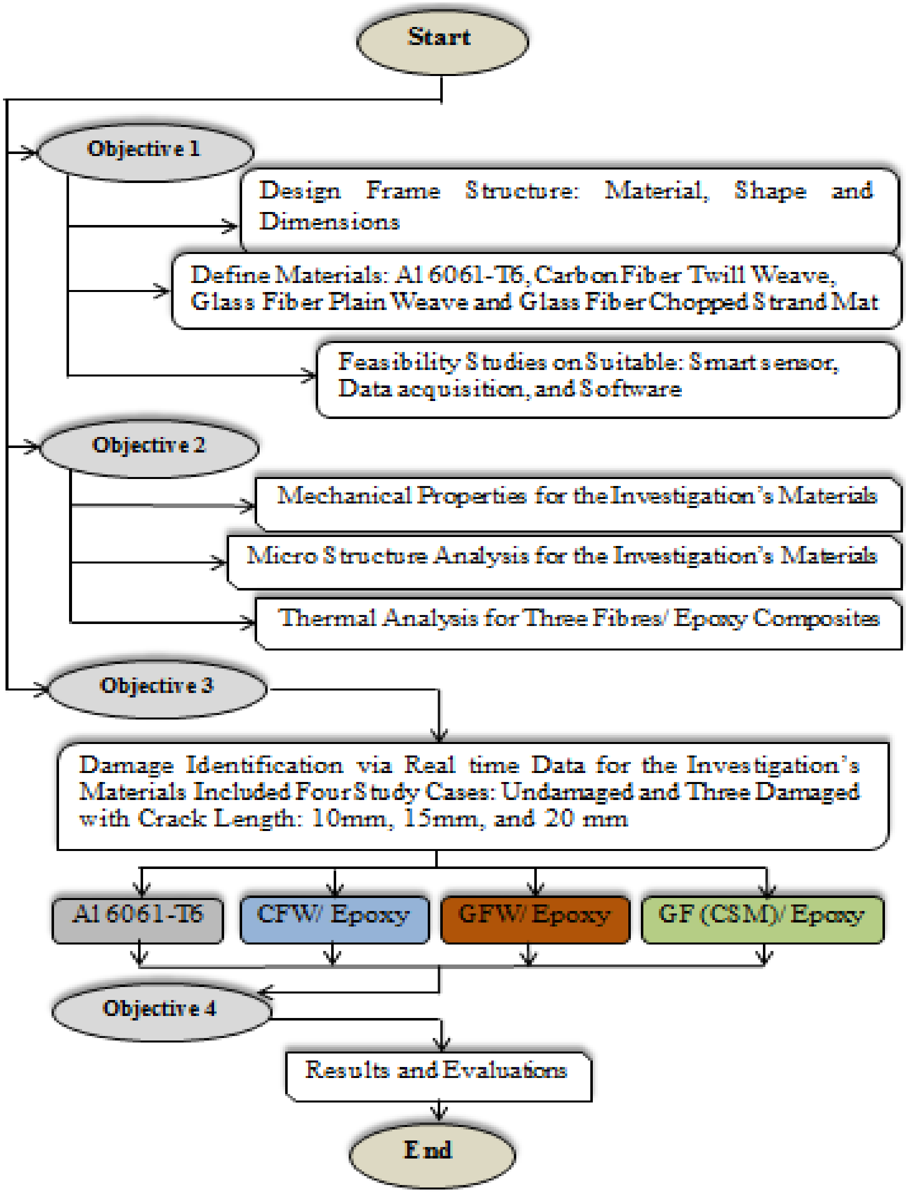

Fig. 1 to illustrate the research's methodology

4.1 Composite Materials and Fabrication Method

Three types of fibre reinforce materials (twill weave carbon, plain weave and chopped strand mats glass fibres) and epoxy resin (EpoxAmite®100 A and Hardener 103 slow type B) was selected to fabricate composite panels. Hand lay-up method and vacuum bagging process were selected to fabricate the three types of fibers reinforced epoxy laminated composites. The design has been done to achieve and gain the most important factor that it is the thickness of fabricated composite.

4.2 Mechanical Properties Tests

The mechanical properties of Al 6061-T6 and three fabricated laminated composites were examined using the following tests:

4.2.1 Tensile Strength: according to ASTM D 3039/D 3039M– 00 standard test methods, then Young's Modulus (E) and Poisson's Ratio (v) were obtained.

4.2.2 Flexural Strength: according to ASTM D 790- 00, a standard test method.

4.2.3 Vickers Hardness: according to ASTM E 384- 99 standard test method.

4.2.4 Impact Izod Pendulum: according to ASTM D 256-04 standard test method.

4.2.5 Specific of Gravity (Relative Density) and Density (ρ): according to ASTM D 792- 00 standard test methods.

4.2.6 Water Absorption: according to ASTM D 570- 98 standard test methods.

4.2.7 Void Content: according to ASTM D 2734- 94 standard test method.

4.3 Micro Structure Analysis

Recently, structural engineers have considered the composites micro structure analysis as the most important properties to evaluate and enhance the importance of composites.

4.3.1 Scanning Electron Microscopy (SEM).

4.3.2 Energy Dispersive Spectrometer (EDS).

4.3.3 X-Ray Diffraction (X-RD)

4.4 Thermo Plastic Analyses

An unknown polymer composite can be identified using thermo plastic analysis using dynamic mechanical analysis and thermo gravimetric analysis.

4.4.1 Dynamic Mechanical Analysis (DMA)

4.4.2 Thermo Gravimetric Analysis (TGA)

4.5 Frame Structure's Design and Setup

In-house, mechanical vibration exciter with industrial motor Model BALDOR and speed controller a square platform were used to setup the structure's frame. The shaker's platform was modified to setup the aluminium frame. The three-storey frame experimental setup was used for the four types of materials. The experimental setup included the frame with composite panels as three floors. These panels were changed and fixed individually based on the same material for the three floors. PZT sensor was bonded on the surface of 3rd floor. This PZT was connected by wire to the NI USB-9234 DAQ, while it was USB linked to the PC and LabVIEW SignalExpress software was installed. In Fig. 2 the experimental setup was demonstrated.

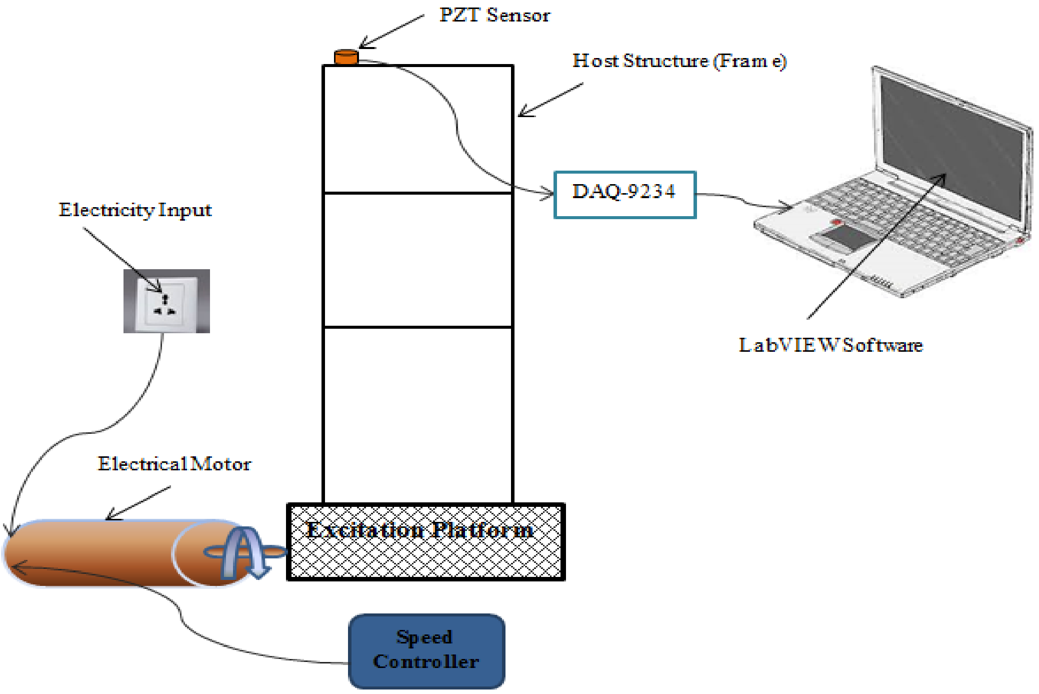

Fig.2 Proposed Diagram of Structural Health Monitoring system.

4.6. Data Acquisition and Damage Detection

In general, the signals were filtered and it was in acceleration function and time domain. Power spectrum presented vs frequency for 13000 Hz and the zoom spectrum was selected between intervals 1000 HZ to 6000 Hz. Then, the Coherence was demonstrated as amplitude vs frequency start from 0 to 13000 Hz as the signal's test limitation. Filtered signals, power spectrum, zoom power spectrum, and coherence were detected for the four case studies. Comparision between the four investigated materials in case: undamaged, crack 10mm, crack 15mm, and crack 20mm were compared.

4.7 Statistical Analysis and Damage Identification

The damage identification is one objective of this study in order to predict the structures integrity. To gain this aim, two methods for evaluation and acquisition are used: Frequency Reduction Index (FRI) and Root Mean Square Deviation (RMSD) index as statistical analysis.

4.7.1 Root Mean Square Deviation (RMSD) Index

The mean is a helpful function to organize and analysis a large sets of data. RMS value of various signals can be taken as equally spaced samples. The mean (average) was achieved by dividing the sum of observations and the number of these observations (n). The standard deviation was defined as the average distance between the real data and the mean. Mostly, Root Mean Square Deviation (RMSD) as a non-parametric measurement was used to quantify damage (Min et al., 2011; Neto et al., 2011; Annamdas, et al., 2010; Panigrahi et al., 2010; Yang et al., 2010; Baptista and Filho, 2009; Park, 2006; Giurgiutiu, and Zagrai, 2005; Rutherford et al., 2004; Caccese, et al., 2004; Naidu, and Soh, 2004; and Raju, 1997). The damage matrices vary according to number of points contained in the related measurements. Normally, impedance measurements shift slightly in the vertical level or lateral level when the damage occurred (Peairs, 2006).

4.7.2 Frequency Reduction Index (FRI)

The natural frequency describes the global properties of the structure. Natural frequency can be changed due to any presence of damage which effect on the structure properties. The damage magnitude can be obtained from the calculation for the Frequency Reduction Index (FRI), AL-Talah, (2010).

5. CONCLUSION

This study adopted an alternate process for damage detection and identification of fabricated composite structures based on SHM technique. The significance of vibration effects on selected specimens provide the effectiveness of the SHM system for damage identification and for composite panels statistical analysis is used to compare the results with an Al 6061-T6 panel's results. The study demonstrated that composites can be used as floor panels for light weight and meet the requirements, together with significant weight savings. A good performance is observed for carbon fibre/epoxy structure. From the results, it is observed that the carbon fibre/epoxy composite is lighter and more strength than that of two types of the glass fibres/epoxy with similar design and thickness specifications. The results showed that RMSD and FRI are an acceptable statistical analysis to evaluate the structures integrity.

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REFERENCES

[1] Ali, M. M., and Moon, K. S. (2007). Structural developments in tall buildings: current trends and future prospects. *Architectural Science Review*, 50(3), 205-223.

[2] AL-Talah, Z. A. (2010). *Damage identification and localization of Cantelever Steel beam with Circular Cross Section Using Modal analysis*. Master Thesis, Universiti Putra Malaysia.

[3] Annamdas, V. G. M., and Soh, C. K. (2010). Application of electromechanical impedance technique for engineering structures: review and future issues. Journal of Intelligent Material Systems and Structures, 21(1), 41-59.

[4] Annamdas, V. G. M., Yang, Y., and Soh, C. K. (2010). Impedance based concrete monitoring using embedded PZT sensors. *International journal of civil and structural engineering.* 1(3): 414-424.

[5] Baptista, F. G. and Filho, J. V. (2009). A new impedance measurement system for PZT-based structural health monitoring. *Instrumentation and Measurement, IEEE Transactions on*, 58(10), 3602-3608.

[6] Caccese, V., Mewer, R., and Vel, S. S. (2004). Detection of bolt load loss in hybrid composite/metal bolted connections. *Engineering Structures*, 26(7), 895-906.

[7] Dong, Y., Song, R. and Liu, H. Bridges Structural Health Monitoring and Deterioration Detection Synthesis of Knowledge and Technology, Final Report, December 2010, Alaska University Transportation Center. Retrieved 31 Jan 2015 from: http://ine.uaf.edu/autc/files/2011/08/Final_Report_3090361.pdf

[8] Crider, I., & Jeffrey, S. (2007). *Damage detection using Lamb waves for structural health monitoring*: DTIC Document.

[9] Giurgiutiu, V. (2005). Tuned Lamb wave excitation and detection with piezoelectric wafer active sensors for structural health monitoring. *Journal of Intelligent Material Systems and Structures*, 16(4), 291-305.

[10] Giurgiutiu, V., and Zagrai, A. (2005). Damage detection in thin plates and aerospace structures with the electro-mechanical impedance method. *Structural Health Monitoring.* 4(2): 99-118.

[11] Giurgiutiu, V., and Zagrai, A. N. (2002). Embedded self-sensing piezoelectric active sensors for on-line structural identification. *Journal of Vibration and Acoustics,* 124(1), 116-125.

[12] Giurgiutiu, V. and Zagrai A. (2001). Electro-Mechanical Impedance Method for Crack Detection in Metallic Plates. *SPIE's 8th Annual International Symposium on Smart Structures and Materials and 6th Annual International Symposium on NDE for Health Monitoring and Diagnostics*, 4-8 March 2001, Newport Beach, CA. paper # SS02 4335-22.

[13] Giurgiutiu, V., and Zagrai, A. N. (2000). Characterization of piezoelectric wafer active sensors. *Journal of Intelligent Material Systems and Structures,* 11(12), 959-976.

[14] Kessler, S. S., Spearing, S. M., Atalla, M. J., Cesnik, C. E., & Soutis, C. (2002). Damage detection in composite materials using frequency response methods. *Composites Part B: Engineering,* 33(1), 87-95.

[15] Kirikera, G. R., Shinde, V., Schulz, M. J., Ghoshal, A., Sundaresan, M. J., and Allemang, R. J., (2008). A structural neural system for real-time health monitoring of composite materials. *Structural Health Monitoring,* 7(1), 65-83.

[16] Mascareñas, D. L. (2006). *Development of an impedance method based wireless sensor node for monitoring of bolted joint preload.* Master Thesis. Structural Engineering, University of California, San Diego, USA.

[17] Min, J., Shim, H., and Yun, C.-B. *Electromechanical Impedance-based Damage Identification Using Multiple Piezoelectric Sensors*. The 6th International Workshop on Advaced Smart Materials and Smart Structures Technology (ANCRiSST 2011) July 25-26, 2011, Dalian. China.

[18] Mufti, A. A. (2002). Structural health monitoring of innovative Canadian civil engineering structures. *Structural Health Monitoring,* 1(1), 89-103.

[19] Mustapha, F., Manson, G., Worden, K., and Pierce, S. (2007). Damage location in an isotropic plate using a vector of novelty indices. *Mechanical Systems and Signal Processing,* 21(4), 1885-1906.

[20] Mustapha, F., Manson, G., Pierce, S., and Worden, K. (2005). Structural health monitoring of an annular component using a statistical approach. *Strain,* 41(3), 117-127.

[21] Naidu, A., and Soh, C. (2004). Damage severity and propagation characterization with admittance signatures of piezo transducers. *Smart Materials and Structures,* 13(2), 393.

[22] Neto, R. M. F., Steffen, V., Rade, D. A., Gallo, C. A., and Palomino, L. V. (2011). A low-cost electromechanical impedance-based SHM architecture for multiplexed piezoceramic actuators. *Structural Health Monitoring,* 10(4), 391-402.

[23] Panigrahi, R., Bhalla, S., and Gupta, A. (2010). A Low-Cost Variant of Electro-Mechanical Impedance (EMI) Technique for Structural Health Monitoring. *Experimental Techniques,* 34(2), 25-29.

[24] Park, G., Farrar, C. R., di Scalea, F. L., and Coccia, S. (2006). Performance assessment and validation of piezoelectric active-sensors in structural health monitoring. *Smart Materials and Structures.* 15(6): 1673.-1683.

[25] Park, G., and Inman, D. (2001). Smart bolts: an example of self-healing structures. *Smart Materials Bulletin,* 2001(7), 5-8.

[26] Peairs, D. M. (2006). *High frequency modeling and experimental analysis for implementation of impedance-based structural health monitoring.* PhD. Dissertation, Virginia Polytechnic Institute and State University.

[27] Raju, V., (1997). *Implementing Impedance-based Health Monitoring*, Master's thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

[28] Rutherford, A. C., Park, G., Sohn, H., & Farrar, C. R. (2004). *The Use of Electrical Impedance Moments for Structural Health Monitoring.* Paper presented at the Proceedings of the 22nd IMAC.

[29] Silva, C., Rocha, B., and Suleman, A. (2011). PZT Network and Phased Array Lamb Wave Based SHM Systems [9th International Conference on Damage Assessment of Structures (DAMAS 2011)]. *Journal of Physics: Conference Series* (305), *012087 IOP Publishing*.

[30] Silva, C., Rocha, B., and Suleman, A. (2010). *Guided Lamb Waves Based Structural Health Monitoring Through a PZT Network System.* Paper presented at the 2nd International Symposium on NDT in Aerospace.

[31] Song, G., Sethi, V., and Li, H.-N. (2006). Vibration control of civil structures using piezoceramic smart materials: A review. *Engineering Structures,* 28(11), 1513-1524.

[32] Sun, M., Staszewski, W., and Swamy, R. (2010). Smart sensing technologies for structural health monitoring of civil engineering structures. *Advances in Civil Engineering, 2010*. Hindawi Publishing Corporation, Advances in Civil Engineering, Volume 2010, Article ID 724962, 13 pages.

[33] Wang, D., Song, H., & Zhu, H. (2014). Embedded 3D electromechanical impedance model for strength monitoring of concrete using a PZT transducer. *Smart Materials and Structures, 23*(11), 115019.

[34] Yan, S., Wu, J., Sun, W., Ma, H., and Yan, H. (2013). Development and Application of Structural Health Monitoring System Based on Piezoelectric Sensors. *International Journal of Distributed Sensor Networks,* (12pp).

[35] Yan, W., and Chen, W. (2010). Structural health monitoring using high-frequency electromechanical impedance signatures. *Advances in Civil Engineering, 2010*. 11page.

[36] Yang, Y., Divsholi, B. S., and Soh, C. K. (2010). A reusable PZT transducer for monitoring initial hydration and structural health of concrete. *Sensors,* 10(5), 5193-5208.

[37] Yang, Y., Liu, H., Annamdas, V. G. M., and Soh, C. K. (2009). Monitoring damage propagation using PZT impedance transducers. *Smart Materials and Structures,* 18(4), 045003, (9pp).