UNIVERSITI TEKNIKAL MALAYSIA MELAKA

EXPERIMENTATION OF MODE SHAPE CURVATURE ALGORITHM USING ACCELEROMETER FOR DAMAGE DETECTION IN ALUMINIUM 6061

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours.

by

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APPROVAL

This report is submitted to the Faculty of Mechanical and Manufacturing Engineering Technology of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for degree of Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours. The member of the supervisory is as follow:

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ABSTRAK

Pemantauan Kesihatan Struktur telah digunakan dalam pelbagai aplikasi seperti aeroangkasa, jentera dan struktur awam untuk mengekalkan keselamatan dan integriti struktur. Objektif eksperimen ini adalah untuk mengesan kerosakan pada spesimen dengan satu takuk sepanjang 150 mm dan spesimen dengan dua takuk sepanjang 150 mm dan untuk melakukan eksperimen pada specimen yang tidak rosak dan rosak menggunakan kaedah pengujaan (pukulan tukul) manakala skop eksperimen ini adalah menggunakan aluminium 6061 sebagai bahan eksperimen, membuat takuk menggunakan mesin CNC dan menjalankan eksperimen menggunakan kaedah pengujaan (pukulan tukul) dan meter pecutan (sensor piezoelektrik) untuk mengesan kerosakan pada specimen yang rosak dan tidak rosak. Kaedah ujian getaran termasuk kajian mod, kajian resonans dan kaedah pengujaan sementara bagi pengesanan kerosakan kekrapan semulajadi, nisbah redaman dan kaedah pemetaan ruang telah digunakan. Bentuk mod akan dianalisis dengan menggunakan unsur terhingga, transformasi laplace, regresi teguh dan polynomial kubik. Metodologi eksperimen ini bermula dari pengumpulan maklumat, pemilihan bahan dan reka bentuk, fabrikasi, ujian getaran dan hasil yang diperoleh dan ujian getaran menggunakan kaedah tukul roving.

ABSTRACT

Structure Health Monitoring (SHM) has been applied in various applications such as aerospace, machinery and civil structures to maintain structure's safety and integrity. The objective of this experiment is to detect damage in specimen with single 150 mm notch and specimen with double 150 mm notch and to conduct experiment on undamaged and damaged specimen using excitation method (impact hammer) meanwhile the scope of this experiment is to use aluminium 6061 as experiment material, fabricate the material using CNC machine and conduct experiment using excitation method (impact hammer) and accelerometer (piezoelectric sensor) to detect damage on undamaged and damaged specimen. Vibration testing method include mode studies, resonance studies and excitation method meanwhile for damage detection natural frequency, damping ratio and gapped smoothing method has been use. The mode shape will be analysis using finite element, laplace transform, robust regression and cubic polynomial. The methodology of this experiment start from gathering the information, material selection and design, fabrication, vibration test and result obtain. The material was fabricated using CNC machine and the vibration test used roving hammer method.

DEDICATION

To my beloved parents Afandi Bin Elias and
Nor'aidah Binti Rosdi and all my friends.

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Praise to Allah SWT the Almighty for his blessing in giving me the strength, ideas, determination and patience in completing this last semester project paper in which to the graduation requirement of Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours.

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mm	-	millimeter
g	-	gram

LIST OF ABBREVIATIONS

BC	Before Century
BVID	Barely Visible Impact Damage
VBDD	Vibration Based Damage Detection
CNC	Computer Numerical Control
FFT	Fast Fourier Techniques
SHM	Structural Health Monitoring
NDI	Non-Destructive Inspection
GSM	Gapped Smoothing Method
PSF	Plane Shape Function
DOE	Design Of Experiment
FEM	Finite Element Method
FRF	Frequency Respond Function
CPR	Cubic Polynomial Regression
CF	Chebyshev Filters

CHAPTER 1

INTRODUCTION

1.0 Introduction

This chapter will discuss briefly about the history of transportation before the creation of wheel to new type of transportation in the 17th century and type of damage in transportation such as minor damage, moderate damage and severe damage. Next the problem statement of this project is stated and then the objective and scope of this project such as what material will be use, what machine will be use, how the experiment conduct and etc. Last but not least, the overview on this chapter.

1.1 Background

Before the creation of wheel, human used to travel on foot from one point to another point. From 4000 BC to 3000 BC, animal such as donkeys, horses and camels had been use by human being as a way of transportation. According to Tim Lambert (2019), horses and donkeys were likely trained between 4000 BC and 3000 BC in the meantime camels were tamed marginally later between 3000 BC and 2000 BC. The first wheel was invented in what is now Iraq around 3500 BC and were made of from solid pieces of wood plane together to form a circle. Spokes were made after 2000 BC. The earliest boats were dugout canoes. It were made from a big log that people lit on fire and then put it out and dug out the burned wood. The Egyptians invented the sailing boat around 3100 BC; meanwhile the Romans built roads across Europe. In the 17th and 18th century, many new type of transportation were invented such as bicycles, trains, motor cars, trucks, airplanes, and trams.

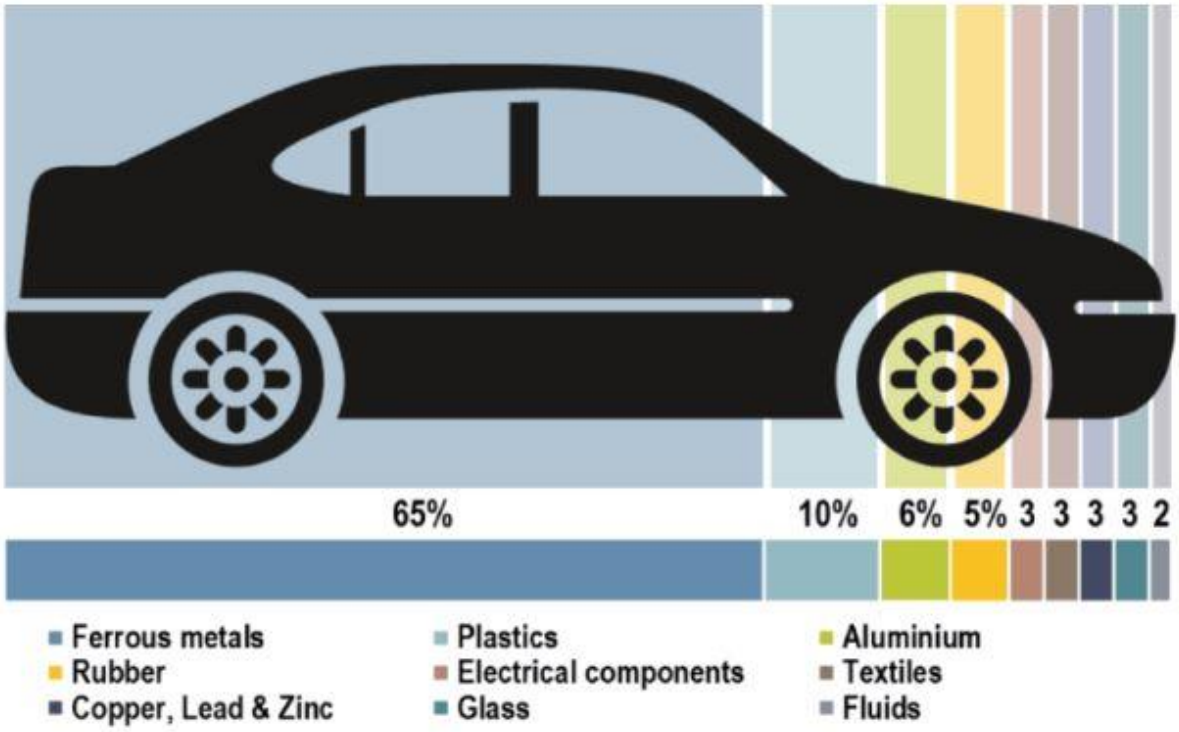

Figure 1.1: Main Material Components of a Car.

According to Paul Rodrigue (2017), an average 1.5 ton car is made of about 100 systems such as engine, transmission, cooling, steering, brake and etc. and between 8000 and 10000 different components. Based on **figure 1.1** ferrous metals or steel, plastics and aluminium cover about 81% of total mass of an average car. Although it was made of from durable and robust material to withstand harsh condition, poor maintenance of the material will start to become endurable.

If transportation had a poor maintenance, it can cause damage on the transportation. Type of damage of transportation is minor damage, moderate damage and severe damage. Minor damage typically means scratches and scrapes for example, a cracked on the headlight or a small dent on the body of vehicle. Moderate damage usually means large dents on the body of vehicle. If the doors won't open, it is more likely to have a moderate amount of damage. Severe damage is a very heavy damage. Example of a heavy damage is broken axles and bent or twisted frames. All three type of damage can be seen with naked eyes. The most dangerous damage is a damage that cannot be seen or barely visible impact damage (BVID). Example of barely visible impact damage is crack inside the body of part. The external surface is untouched, but there is a crack inside.

1.2 Problem statement

Non-destructive inspection technique such as thermography, visual inspection, radiography and ultrasonic does not fit to be used to detect barely visible impact damage. If it can be done, it will be a waste of time. This is because the time taken to locate the damage area is time consuming. Moreover it requires more labours, high cost and the structure need to be out of operations to start the non-destructive inspection operation. For example, the inspection on the wing of an aircraft. The time taken to cover the whole part of the wing is long and the location of the damage area is unknown. Moreover lots of labours are needed, this will increase the maintenance cost. Besides, the aircraft need to be out of operation. The more dwell time of the aircraft the more lost the company need to take. The solution is vibration-based damage detection (VBDD) implementing mode shape curvature in gapped smoothing method algorithm will be used and applied as the technique is baseline-free and sensitive to small size of damage. The use of this technique can reduce the time taken to inspection the part and reduce cost of maintenance, hence optimize the operation time of the transportation.

1.3 Objective

1. To detect damage in specimen with single 150 mm notch and specimen with double 150 mm notch.
2. To conduct experiment on undamaged and damaged specimen using excitation method (impact hammer).

1.4 Scope

1. Use of aluminium 6061 as experiment material.
2. Fabrication using CNC machine.
3. Conduct experiment using excitation method (impact hammer) and accelerometer (piezoelectric sensor) to detect damage on undamaged and damaged specimen.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter will be details some of the most significant work that related to the development of non-destructive damage detection in laminated composite. This chapter start with the background of vibration, desirable and undesirable vibration followed by vibration testing method such as mode studies, excitation method and resonance studies. Next the background of laminated composite followed by damage type in composite. Next, the damage detection in composites will be reviewed such as gapped smoothing method, natural frequency and damping ratio. After that review about mode shape and method that had been used before such as finite element, laplace transform, robust regression and cubic polynomial.

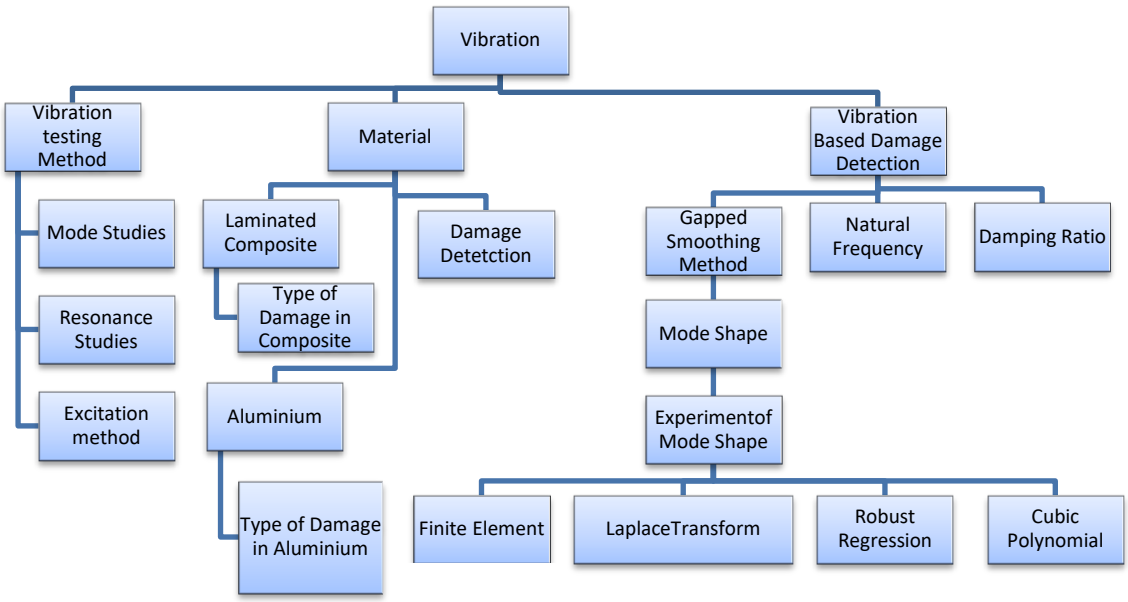

Figure 2.1: K-chart

2.1 Background of Vibration

Vibration in its most straightforward structure can be viewed as the swaying or dreary movement of an object about a balance point. The equilibrium or harmony position is the situation of an object when there is zero power following up on it. An excitation force always caused an object to vibrate. Externally force applied to the object may cause vibration or the force itself may originate from inside of the object.

Vibration can be desirable or undesirable. Example for desirable vibration is movement of a tuning fork, the reed in a woodwind instrument or harmonica, a cell phone, or the cone of an amplifier. However for undesirable vibration, it waste energy and create unwanted sound. For example, the vibrations in body part of an aeroplane are typically unwanted. Such vibration can cause by unseen damage or crack that are not visible to naked eyes. When an aeroplane is in operation with the unseen damage, catastrophe can happen.

2.2 Vibration Testing Method

There are many methods used in vibration testing such as mode studies, resonance studies, excitation methods and etc. Mode studies is a study on the estimation of versatility or mechanical impedance gives the recurrence reaction work between the purpose of excitation and another point superficially as shown in **figure 2.2**. Be that as it may, recurrence reaction capacity exists between all points of the surface and it will result a very large number of function. Therefore data reduction is necessary to describe the modes of the structure. Mode shape is a vibration shape of a structure at particular frequencies. It is call resonance of the structure and it is indicated as minima on the mechanical impedance curves and maxima on the mobility curves.

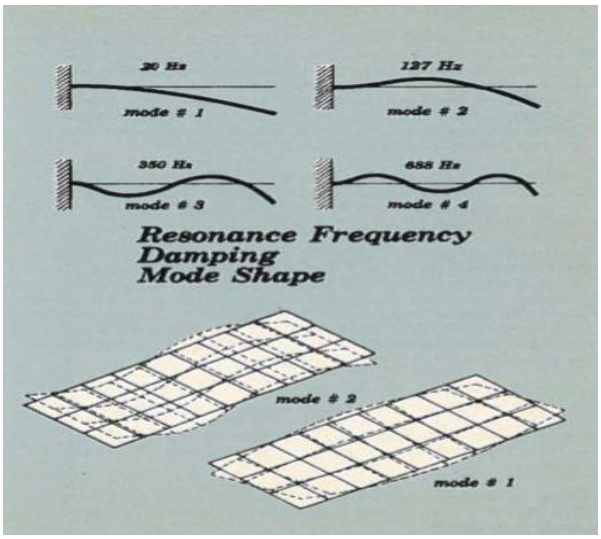

Figure 2.2: Resonance frequency damping mode shape.

Resonance studies are a study on characteristic of a structure. Reverberation or resonance is the expansion of vibration abundancy and the difference in stage among power and reaction. Higher damping gives a lower and more extensive pinnacle and a stage change over a more extensive recurrence extend. Adequate information of well separated resonances given by amplitude and a phase curve, but the information for curves with resonance is difficult to interpret because the peak is strongly overlapping.

Excitation methods apply sine or a broad band signal to provide the force input to the structure to be analysed. Fast Fourier Techniques (FFT) was used to measure and analysed the input as well as the output. The recurrence reaction or frequency response is determined from the input spectrum, estimated with a force transducer and the yield range regularly estimated with an accelerometer. As shown in **figure 2.3** an impact hammer integrally mounted with a force transducer can produce a broad band excitation instead of using an exciter. The impact method is fast, the set-up time is minimal and the amounts of equipment are small. The drive or impulse contains vitality or energy at all frequencies and will along these lines energize and excite all modes at the same time. Anyway the sign to clamour proportion is poor and for delicate structures with a high level of damping it tends to be difficult to get an adequately huge reaction without harming this test object. The vibration exciter strategy has a high sign to commotion proportion, a simple control with a decision of excitation waveforms and the probability of energizing a few

points simultaneously. Despite the excitation technique the reaction ought to be performed at a few points on the structure to get the mode shape.

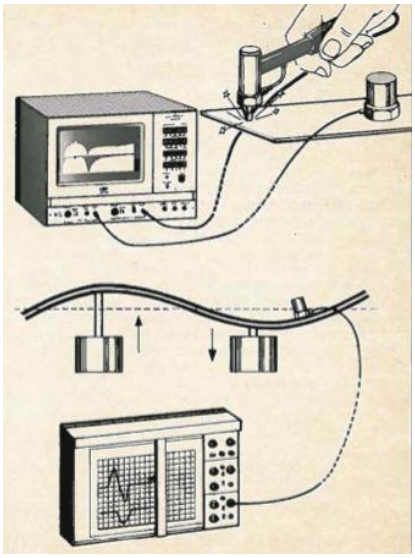

Figure 2.3: Excitation method using impact hammer.

2.3 Material

A chemical substance or mixture of substances that constitute an object is material. In industry, material comes as raw material which is unprocessed or already processed. Then it will be used in production or manufacturing process.

2.3.1 Laminated Composite

2.3.1.1Background of Laminated Composite

Laminated composite is layers of fibrous composite materials as shown in **figure 2.4** which combine into one material to give required engineering properties, for example, plane solidness, twisting firmness, quality, and coefficient of thermal development. According to Chris Woodford (2018), laminates is a strong and durable material that consists of different layer that are bonded together with adhesive meanwhile composite is the final product which is made by combining two or more laminated materials that improve one another but keep distinct and separate identities.

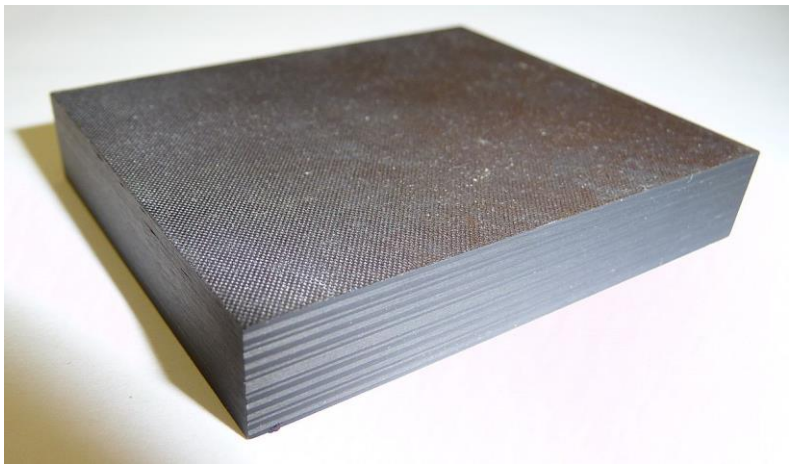

Figure 2.4: Laminated Composites.

2.3.1.2 Type of Damage in Composite

Damage mechanism in composite material are not well understood compare to metal where the damage mechanism is simpler than composite. During the fabrication process of composite material, defect can occur. Porosity is the most common one. Porosity is the presence of a void in the matrix. Jeongguk K et al. (2003) say that incorrect or non-optimal curing parameters can cause porosity. Damage also can occur during service life of composite material where it happens due to impact. Delamination is the common defect due to impact. Delamination or barely visible impact damage (BVID) is a separated layered as shown in **figure 2.5**, where mica-like structure was formed with a significant loss in mechanical properties. Fatigue and lightning strikes also can cause damage to composite material. A study by Kim and Hwang (2006) say, it can significantly reduce the mechanical properties of the composite structures in which it can potentially lead to catastrophic accident.