THE EFFECT OF HIGH FREQUENCY WAVE IN VIBRO ACOUSTIC METHOD FOR CRACK DETECTION

NURUL HUSNINA BINTI ANUAR

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

THE EFFECT OF HIGH FREQUENCY WAVE IN VIBRO ACOUSTIC METHOD FOR CRACK DETECTION

NURUL HUSNINA BINTI ANUAR

A report submitted
in fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering (Plant & Maintenance)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2017

DECLARATION

I declare that this project report entitled "The Effect Of High Frequency Wave In Vibro Acoustic Method For Crack Detection" is the result of my own work except as cited in the references

Signature	:	....
Name	:	Nurul Husnina Binti Anuar
Date	:	....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Plant & Maintenance).

Signature :. ....

Name of Supervisor : Dr. Ruztamreen Bin Jenal

Date : ....

DEDICATION

To my beloved family for the endless support they had gave

ABSTRACT

The most common structural defect is the existence of fatigue crack. Fatigue cracks can present in the structures due to various reasons. The presence of cracks is hazardous as it can affect the mechanical behaviour of the entire structure to a considerable extent, thus a non-linear vibro-acoustic approach suitable for detecting the presence of fatigue crack as they are very sensitive even to a small damage severities or cracks and highly reliable method. This study is carried out to study about crack detection on a structure by using a non-linear vibro-acoustic technique. Vibro-acoustic method is a method based on propagation of high frequency acoustic waves in solid structures with low-frequency excitation. The interaction occur between the acoustic waves with material changes will cause wave distortion effects. The main objective of this study to find effects of high frequencies against the non-linear effects sensitivity using variation of high frequency wave in vibro-acoustic method to detect the fatigue crack. The test specimen that will be used in this study is a 150 mm x 400 mm x 2 mm aluminium plate (AL-2024). The plate will undergo some modal analysis to determine the dynamic response of a material and followed by the vibro-acoustic test. In addition, this study also will provide analysis on the relation of high frequency effect and the amplitude modulation intensity (R-value). The findings show that crack exhibited in a power spectra signal of the acoustic response by a pattern of sidebands around the ultrasonic signal and explains that the high frequencies excitation does not give significant change on the modulation intensity but proper selection of the high frequency excitation value and also its location is important to obtain a good result.

ABSTRAK

Kecacatan struktur yang paling biasa ialah retak lesu. Retak lesu boleh hadir dalam struktur disebabkan oleh pelbagai sebab. Kehadiran retak adalah berbahaya kerana ia boleh mempengaruhi tingkah laku mekanikal struktur keseluruhan ke tahap yang besar, oleh itu suatu pendekatan bukan sekata vibro-akustik sesuai untuk mengesan kehadiran retak kerana ia sangat sensitif walaupun untuk kerosakan kecil atau retak dan kaedah yang boleh dipercayai. Kajian ini dijalankan untuk mengkaji mengenai pengesanan retak pada struktur dengan menggunakan teknik vibro-akustik bukan sekata. Vibro-akustik adalah satu kaedah berdasarkan pengujaan gelombang akustik frekuensi tinggi dan rendah secara serentak kedalam struktur yang kukuh. Interaksi yang berlaku antara gelombang akustik dengan perubahan bahan akan menyebabkan kesan gelombang herotan. Objektif utama kajian ini untuk mencari kesan frekuensi tinggi terhadap sensitiviti kesan bukan sekata menggunakan variasi gelombang frekuensi tinggi dalam kaedah vibro-akustik untuk mengesan keretakan. Spesimen ujian yang akan digunakan dalam kajian ini ialah 150 mm x 400 mm x 2 mm plat aluminium (AL-2024). Plat akan menjalani beberapa analisis modal untuk menentukan gerak balas dinamik yang penting dan diikuti dengan ujian vibro-akustik. Di samping itu, kajian ini juga akan menyediakan analisis mengenai hubungan kesan frekuensi tinggi dan keamatan modulasi amplitud (nilai R). Keputusan menunjukkan bahawa retak dipamerkan di isyarat kuasa spektrum sambutan akustik oleh corak jalursisi sekitar isyarat ultrasonik dan menjelaskan bahawa frekuensi pengujaan tinggi tidak memberi perubahan yang besar ke atas keamatan modulasi tetapi pemilihan yang sepatutnya bagi nilai pengujaan frekuensi tinggi dan juga lokasi adalah penting untuk mendapatkan hasil yang baik.

ACKNOWLEDGEMENT

First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor Dr Ruztamreen Bin Jenal for his essential supervision, support and encouragement towards the completion of this final year project, giving me the space to grow intellectually and independently.

Besides that, I would like thank to Faculty Mechanical Engineering of University Teknikal Malaysia Melaka (UTeM) for giving this opportunity to do this project and providing me with a good environment and facilities to complete this project. Also, I would like to thank En. Azhar and Tino Hermanto for all the valuable information and guidance, which help me in completing the task through various stages.

Lastly, I would also like to thank my family and friends for their patience, encouragement and continuous support regardless of any condition for me to complete this project.

CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBEREVATIONS

SHM	Structural Health Monitoring
NDE	Non-Destructive Evaluation
NDT	Non-Destructive Testing
AE	Acoustic Emission
UT	Ultrasonic Testing
RT	Radiography Technique
IT	Infrared Thermography
EDM	Electronic Discharge Machine
UTM	Universal Testing Machine
PSB	Persistent Slip Bands
VAM	Vibro-Acoustic Modulation
FEM	Finite Element Method
FE	Finite Element
IM	Impact Modulation
SLDV	Scanning Laser Doppler Vibrometer
PZT	Piezoceramic Transducer
HF	High Frequency
LF	Low Frequency
FRF	Frequency Response Function

CHAPTER 1

INTRODUCTION

1.1 Background

Structural health monitoring (SHM) is one of the common approach which being explored as techniques in assessing the integrity of mechanical, civil, and aerospace structures. SHM is the process of damage detection and characterization of the damage for further maintenance strategies. Yu, L. and V. Giurgiutiu (2009) claim that, various SHM methods can be used for crack detection by utilizing piezoelectric sensors. SHM can detect or quantify damage by comparing current structural state measurements to measurements collected from an undamaged structure (Raghavan et al., 2007).

SHM techniques can reduce cost and increase availability by eliminating unnecessary structural inspections. Previous study by Hamey et al (2004) found that SHM also provide a better understanding of the current operational state of the structure thus reducing the probability of catastrophic failures. SHM and Non-Destructive Evaluation (NDE) utilize similar methods and techniques but with several notable differences. For instance, SHM systems typically utilize sensors which are permanently bonded to the structure of interest but unlike NDE. In general, the process of SHM is started by exciting the structure using actuators or operational loading. Then, the response to the excitation will be sensed at various locations throughout the structure. The response signals are collected and processed, and based on the processed data, the state of the structure is diagnosed.

Non-Destructive Testing/Evaluation (NDT/NDE) is a method that evaluates the structure properties without causing damage. There are several of damage detection methods or damage monitoring systems which can be used to measure structural damage such as dye penetrant, Acoustic Emission (AE), Ultrasonic Testing (UT), Radiography Technique (RT), Vibro-acoustic and also Infrared Thermography (IT). However, all these techniques have limitations and are not possible in some situations.

Wevers (1997) described AE as a method to measure the mechanical stress waves that result when strain energy is released due to micro-structural changes in a material. The ultrasonic stress waves will propagate through the structural component and sensed by piezoelectric sensors. Measured data from AE method is often difficult to interpret due to the presence of ultrasonic energy with similar frequencies to those emitted by the release of strain energy. The AE method has found common use as an inspection method for pipelines, pressure vessels, and similar applications, where pressure sensitive structural components can be monitored without the presence of significant environmental noise (Aljets et al., 2012).

If the cracks are on the surface of non-porous materials, a dye penetrant can be done to reveal it. Dye penetrant testing can detect small cracks but only capable of detecting damages on the surface. Dye penetration works by applying colour or fluorescent dye into the surface flaws. After that a post-penetrant material was applied and the flaws will appear as coloured lines.

Infrared thermography is an application through the concept of energy emission. Every object that will be determined emits an amount of energy that will be detected by an infrared camera. Later, the energy emitted will be converted to temperature in form of a temperature distribution or so called “Thermogram”. A red colour of distribution means temperature for that particular point is at low temperature while the red colour determines high temperature for that particular point.

Another method is by using the Lamb wave. Lamb wave is a special kind of guided wave which can be travel over a long distance. The sensitivity of lamb wave to defects is greater than common ultrasonic method. Lamb wave inspection is fast and its cost is so lower than common ultrasonic techniques or other inspection methods. There are two techniques in lamb wave testing which are pulse-echo and emission with different lamb modes as transmitter and receiver.

1.2 Problem Statement

The most common structural defect is the existence of fatigue crack. Fatigue cracks can present in the structures due to various reasons. The presence of cracks will cause a local variation in the stiffness and can affect the mechanical behaviour of the entire structure to a considerable extent. Thus, a non-linear vibro-acoustic approaches are especially well suited for detecting the presence of fatigue crack as they are very sensitive even to a small damage severities and this approach do not require dense sensor networks. However, there are no thorough studies on investigating the effects of high frequencies against the non-linear effects sensitivity, thus this study is carried out to investigate the effect of using variation of high frequency wave in vibro-acoustic method to detect the fatigue crack.

1.3 Objectives

The objectives of this project are as follows:

1. To conduct experiment in detecting fatigue crack, by using the effect of high frequency wave in vibro-acoustic method.
2. To provide analysis on the relation of increasing high frequency value and the effect on the sideband intensity.

1.4 Scope of Project

The scopes need to be cover in this project include:

a. The preparation of the test specimen notch (3 mm) by using Electronic Discharge Machine (EDM).
b. The preparation of the test specimen dynamic fatigue crack by using Universal Testing Machine (UTM).
c. Perform the experimental setup for Modal Analysis to obtain test specimen (aluminium plate) mode shapes and resonant frequencies.
d. Perform the non-linear vibro-acoustic test on the specimen to investigate the effect of using variation of high frequency wave in vibro-acoustic method to detect the fatigue crack.
e. Analysis of the experimental data to obtain the non-linear wave modulation effect.

CHAPTER 2

LITERATURE REVIEW

2.1 Damage in Structures

Many different methods have been developed for detecting damages in the structures. Damage was defined by Jean Lemaître (2005) as the creation and growth of microvoids or microcracks which will create discontinuities in a homogeneous material. Besides that, damage was also known as structural changes on the material geometric properties of a structural or mechanical system (Sohn et al., 2003). Damage can occur in many ways, such as when the stress applied exceeding the yield stress which resulting changes in the material property (Fatigue Properties, n.d.). One of the primary damages types occur in a structure material is fatigue cracking as illustrated in Figure 2.1. Fatigue crack occur when the structure burdened with cyclic loading that are lower than the ultimate tensile stress, or even the yield stress of the material. The most common form of fatigue crack is probably the fatigue crack that opens and closes under dynamic loading. Fatigue crack life is divided into parts, initiation and propagation. In initiation phase, large number dislocations will pile up and form structures called persistent slip bands (PSB). Budynas et al. (2014) claimed that PSB happened due to movement of material along slip planes. In this period there will be some microcrack growth, but the fatigue cracks are still too small to be visible. In the second period, the crack will be growing until complete failure.

Figure 2.1: Fatigue crack in structure.

The formation of crack can be divided into three distinct modes as shown in Figure 2.2 (Johnson P., 1999). Mode I, the opening crack propagation mode due to the tensile stress. Mode II, sliding mode due to the in-plane shear and Mode III, the tearing mode which arises from out-of-plane shear (Johnson P., 1999).

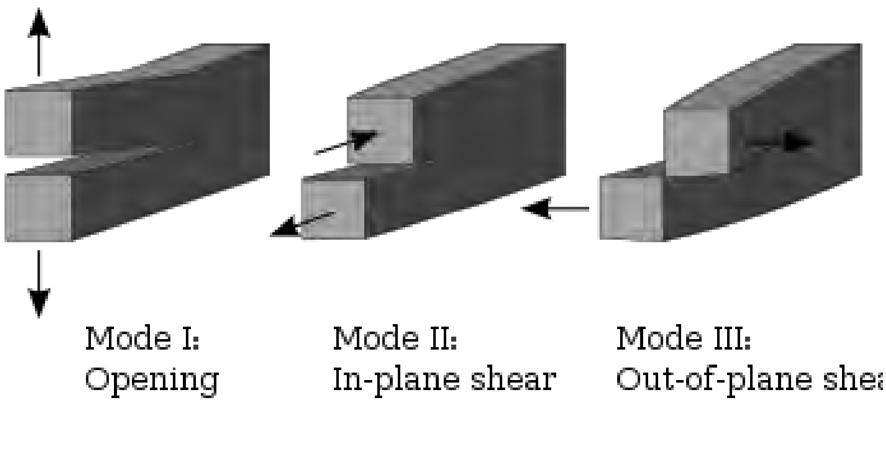

Figure 2.2: Three basic modes for fatigue crack.

2.2 Methods to Detect Fatigue Crack

In the past years, many researchers have shown interest in using non-linear vibration and acoustic phenomena in many research areas including damage detection (Donskoy and Sutin, 1999). Parsons et al. (2006) and Klepka et al. (2011) suggested many different methods have been developed for damage detection in composite structures. Part of the methods are dye penetration, acoustic emission, visual inspection, ultrasonic signals, vibro-acoustic, radiographic methods and also thermography methods. Non-linear acoustic can detect micro damage and early signs of damage. As state in its name, the non-linear is completely the opposite of linear analysis, non-linear technique analyse wave signal output which is unrelated to the signal inputs (Sutin, A.M. and V.E. Nazarov, 1995).

The most common findings from the non-linear effects, which correlated with defects from the non-linear effects, are the side bands generation, amplitude dissipation, harmonics generation and also resonant waves shifting. Some past application of the non-linear acoustics such as, in monitoring the development of fatigue crack by using the second harmonic generation, (Morris et al. 1979); evaluation of concrete material properties by using non-linear ultrasonic parameters, (Korotkov et al. 1994); evaluation of material disruption due to the asymmetry of a lattice structure and dislocation in crystals by using the non-linear acoustic imaging, (Zheng et al. 1999).

2.3 Vibro-acoustic Method

Non-linear vibro-acoustic method is very fast and sensitive in the detecting the cracks. Vibro-acoustic method is a technique which combined the interaction of high frequency wave and low frequency vibration excitation. The two excitations will be induced to the specimen simultaneously as illustrated in Figure 2.3 (L. Pieczonka et al.). The high frequency wave propagated in the specimen is modulated by the low frequency vibration. If there is a presence of crack in the plate, modulation is generated by the non-linear interaction of waves. Frequency sidebands can be observed around the high frequency excitation. In addition to that vibro-acoustic method able to detect structure damaged by measuring the vibration response signal. If the investigated structure is damaged, the spectrum of the response signal will show additional components which are a higher harmonic (K. Dziedziech, 2016). Besides that, previous research done also found that the modulation sidebands obtained from the nonlinear vibro-acoustic can locate the damage (L. Pieczonka et al., 2012) and can obtain the amplitude modulation intensity (R-value) (Klepka, A. et al., 2016). Klepka et al. (2016) claimed that R-value was obtained from the amplitudes of major sidebands obtained from the test and the high frequency component.

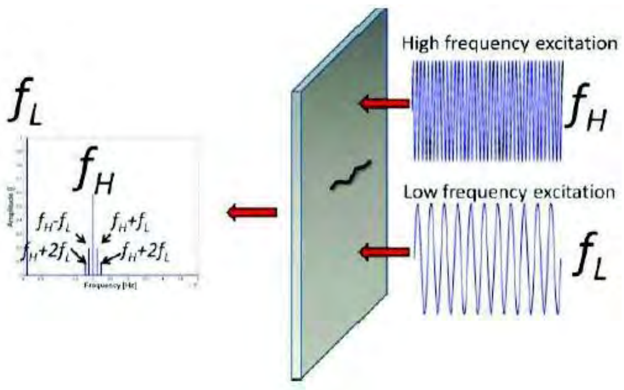

Figure 2.3: The principle of vibro-acoustic modulation (VAM).

Previous researched by Zeng. Chunhua and Zheng. Shijian (1992) state that there are two methods in analysing the structure fatigue under vibration loading. The two methods are time domain method based on the data statistics and the frequency domain method based on the power spectrum density. Yoder (2010) said that VAM is the applying of a lower frequency "pumping" excitation signal and a higher frequency "probing" excitation signal into the structure as shown in Figure 2.4 Yoder (2010). If the structures undamaged it will return a response with energy only at the pumping and probing frequencies. However, in the structure is damaged, additional nonlinear components are created due to nonlinear effects leading to mixing of the two input signals. Yoder also demonstrated that when the ultrasonic signal coincides with the resonant frequencies of the structure, amplitude of the power spectra is magnified (Yoder and Adam, 2010).

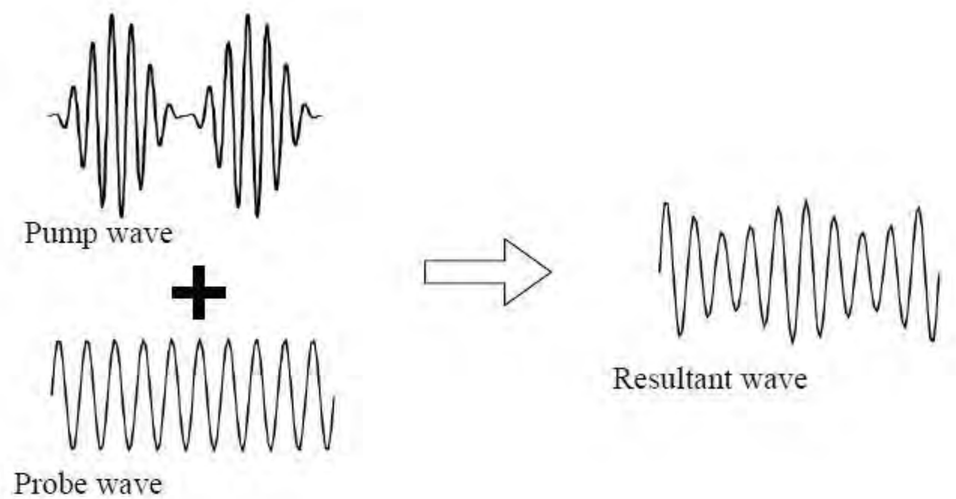

Figure 2.4: Schematic figure of cross modulation between pump wave and probe wave.

There are some previous experimental works for the non-linear vibro-acoustic method. The non-linear experimental works setup used by Donskoy et al. (2001) shown in Figure 2.5. In the experiment setup, low frequency signals introduced by using an impact hammer and the output were received and transmitted by using the piezo-ceramic