EFFECT OF HIGH FREQUENCY INPUT LOCATION FOR CRACK DETECTION IN NONLINEAR VIBRO-ACOUSTIC METHOD

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STUDENT'S DECLARATION

I declare that this project report entitled "Effect of High Frequency Input Location For Crack Detection in Nonlinear Vibro-acoustic Method" is the result of my own work except as cited in the references

Signature : .....

Name : .....

Date : .....

SUPERVISOR'S 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 : .....

Date : .....

DEDICATION

I would like to dedicate this report to my family for being my supporter along the period of handling this Final Year Project. They have always encourage and advice me to do this research succesfully. Next, to my supervisor, Dr. Ruztamreen Bin Jenal that have been always guide me and willingly share his experiences regarding this project research.

ABSTRACT

Fatigue crack can occur due to the material failure to withstand when load is applied repeatedly. There are a few phases in fatigue life of crack; starting from crack initiation, crack growth and rapid fracture. Basically, from the crack motion, three type of crack modes are formed. Mode I is an opening mode. Mode II is mode of sliding. Mode III is mode of tearing. Even though, crack usually seen in smaller size. But, the growth of it can cause major failure of a structure. Therefore, it is essential to perform inspection in detail. Many methods can be used to detect a crack structure. This involve method of laser vibrometer, eddy current and acoustic emission. In this project, vibro-acoustic method is used for crack detection. Therefore, several step needed to be performed. This includes the process of test specimen preparation, modal analysis test and finally vibro-acoustic wave. Generally, the test specimen preparation involve process of material preparation, tensile test, and dynamic fatigue test. This process essential in way to create the crack on the aluminium plate. Next, the plate will be tested on modal analysis to identify the resonant frequencies of the structure. The resonant frequencies will later be used as the excitation of low frequency in the vibro-acoustic test. As for the acoustic signal, 60 kHz will be used in that test. This vibro-acoustic test is chosen to achieve the main objective of the research; to find the effect of high frequency excitation position in crack detection. The output signal formed is then will be transformed in frequency domain using MATLAB software. Finally, the analysed data result in this research proved that the position of high frequency input does not mainly effect the crack detection process.

ABSTRAK

Retak lesu boleh berlaku disebabkan oleh kegagalan bahan untuk bertahan apabila beban digunakan berulang kali. Terdapat beberapa fasa dalam hayat retak lesu; bermula dari permulaan retak, pertumbuhan retak dan kepesatan patah. Pada asasnya, dari gerakan retak, tiga jenis mod retak terbentuk. Mod I ialah mod pembukaan. Mod II adalah mod gelongsor. Mod III adalah cara terkoyak. Walaupun, retak biasanya dilihat dalam saiz yang lebih kecil. Tetapi, pertumbuhan ia boleh menyebabkan kegagalan utama struktur. Oleh itu, ia adalah penting untuk melakukan pemeriksaan secara terperinci. Banyak kaedah boleh digunakan untuk mengesan struktur retak. Ini melibatkan kaedah meter getar laser, arus pusar dan pancaran akustik. Dalam projek ini, kaedah vibro-akustik digunakan untuk mengesan retak. Oleh itu, beberapa langkah perlu dilakukan. Ini termasuk proses penyediaan ujian spesimen, ujian analisis modal dan akhirnya gelombang vibro-akustik. Secara umumnya, penyediaan ujian spesimen melibatkan proses penyediaan bahan, ujian tegangan, dan ujian dinamik hayat. Proses ini penting dalam cara untuk mewujudkan retak pada plat aluminium. Seterusnya, plat akan diuji pada analisis ragaman untuk mengenalpasti frekuensi salunan struktur. Frekuensi salunan kemudian akan digunakan sebagai pengujaan frekuensi rendah dalam ujian vibro-akustik. Bagi isyarat akustik, 60 kHz akan digunakan dalam ujian itu. Ujian vibro-akustik ini dipilih untuk mencapai objektif utama kajian ini; untuk mencari kesan kedudukan pengujaan frekuensi tinggi dalam pengesanan retak. Isyarat keluaran akan dibentuk kemudiannya akan diubah dalam domain frekuensi dalam menggunakan perisian MATLAB. Akhir sekali, data yang dianalisis hasil carian kajian ini membuktikan bahawa kedudukan masukan frekuensi tinggi tidak menjadi keutamaan dalam melaksanakan proses pengesanan retak.

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LIST OF ABBEREVATIONS

FFT	Fast Fourier Transform
CWT	Continuous Wavelet Transform
NEWS	Nonlinear Elastic Wave Modulation Spectroscopy
TRA	Time Reversal Acoustic
MNLW	Modulation Nonlinear Lamb Waves
SHM	Structural Health Monitoring
TSP	Temperature Sensitive Paint
AE	Acoustic Emission
VAM	Vibro-Acoustic Modulation
PZT	Piezoelectric
FRF	Frequency Response Function

LIST OF SYMBOL

f_n	=	resonant frequency at n-th mode
m	=	mass of structure
k	=	stiffness of structure
A_0	=	ultrasonic amplitude
A_1	=	first sideband amplitude on the left of the ultrasonic spectrum
A_2	=	first sideband amplitude on the right of the ultrasonic spectrum
A_3	=	second sideband amplitude on the left of the ultrasonic spectrum
A_4	=	second sideband amplitude on the right of the ultrasonic spectrum

CHAPTER 1

INTRODUCTION

1.1 Background

Fatigue crack is common maintenance problem in industry application such as steam turbine (Bagaviev and Sheng, 2005) steel bridge (Ichinose, et.al, 2007) and beams (Eroglu and Tufekci, 2016). Fatigue crack occur due to compressive loads. The cyclic stress are below the ultimate tensile stress that also can be refer to the strength of the material. The word "fatigue" is relevant to materials cannot withstand or fails at the loads applied repeatedly. The fatigue failure or crack occurs in three phases which includes the initiation of crack, stable crack growth and rapid fracture. There are three form of crack modes which result from motion of a crack. These modes are opening mode (mode I), sliding mode (mode II) and tearing mode (mode III) which shown in Figure 1.1. Mode I form in way of crack face move directly apart from each other in y-direction. Next, mode II refer to a shear stress which are parallel to the plane of the crack and perpendicular to the crack front. Lastly, if the crack faces act perpendicular to the crack front, this is known as mode III.

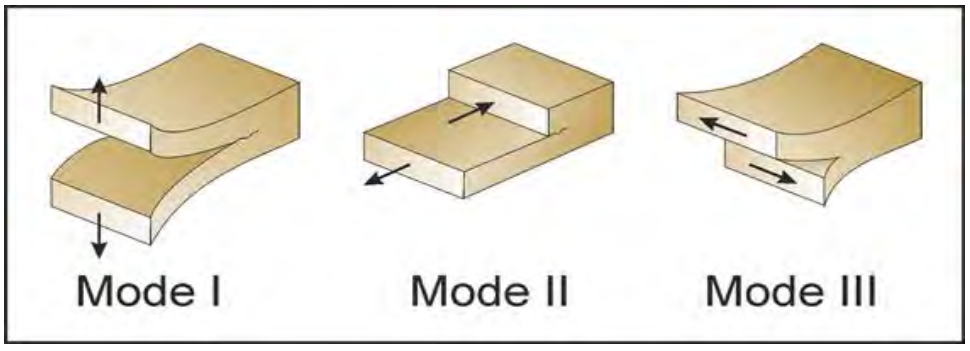

Figure 1.1: Fatigue crack modes.

1.2 Problem Statement

Vibro-Acoustic method technique is a method of introducing two signal frequencies in solid structure for crack detection. The two frequencies are high frequency acoustic wave and low frequency vibration mode. This techniques requires some parameters that can control the non-linear effect such as excitation location of high and low frequency and location of measurement point. However, there are still no detail study that show the effect of high frequency location for crack detection. Thus, this project is carried out to reveal the effect of high frequency location in presence of crack.

1.3 Objective

The objectives of this project is seek to:

1. Create a 20 mm crack at the middle of the plate.
2. Determine the effect of high frequency excitation location in crack detection by using vibro-acoustic method.

1.4 Scope of Project

The scopes of this project are:

1. The preparation of specimen which involve some process that includes cutting an aluminium plate with dimension of 400mm*150mm*2mm , drilling hole using EDM wire cutter, line cutting for fatigue crack initiation and fatigue crack creation.
2. Modal analysis for determination of natural frequency and mode plates and which require an experimental works, theoretical and calculation.
3. Vibro-acoustic test to evaluate the correlation between parameters involves and the nonlinear effect in damage detection.

CHAPTER 2

LITERATURE REVIEW

2.1 Damage in Structure

In diagnose the structural damage, an approach of signal based pattern is determined. Each type of damage will form a unique pattern of itself. This studies in observing the features of frequency-based and time-frequency based. This two features is obtained from vibration signals that form through fast fourier transform (FFT) and continuous wavelet transform (CWT). In comparison of CWT and FFT, CWT have higher resolution of pattern matching because of the preservation of time sensitive and time. (Qiao et al., 2012).

Discontinuity is one of damage in structure where there is a nonlinear dynamic structures. The development of discontinuity in cracked bar can be analysed using nonlinear integral equations and Matlab-Simulink computation (Babitsky and Hiwarkar, 2016).

Damage in plate structure can be detected using Lamb wave and time reversal theory. The complicated of Lamb wave propagation are due to dispersion and multimode feature. Based on this application of time reversal method and propagation of Lamb wave provide clear image of damage and crack position can be detected (Liu et al., 2012).

2.2 Fatigue Crack

(Masserey and Fromme, 2013) states "the growth of fatigue crack can be monitored by using laser interferometer." It has high accuracy which can detect defects of medium with long distances. The propagation of high frequency guided ultrasonic wave can be delivered as a Rayleigh wedge transducer is use for excitation. The growth of fatigue crack can result in signal changes.

Next, the thickness of a crack can be analysed and studied through the Lamb wave propagation. Transmission and reflection mode conversion show the interaction of Lamb waves and crack. This mode of conversions are used to calculate the time domain and frequency coefficients. As result, as the crack length increase, the coefficient of transmission will be decreased. Plus, the diffraction of wave is vital in coefficient of transmission when there is short crack length (Lu et al., 2008).

An aluminium alloy plate in presence of crack can be studied through the combination of nonlinear elastic wave modulation spectroscopy (NEWS) and time reversal acoustic (TRA). The purpose of this methods combination are for better focussing the elastic wave of a crack. PZT transducer were used as the source of excitation and using equipment such as laser vibrometer, computer and digital oscilloscope (Gao et al., 2011). There is also a combination of modulation nonlinear lamb waves (MNLW) and time reversal method in determination of crack on aluminium alloy plate. Basically, the equipment used is the same as combination methods of NEWS and TRA. In this duo-technique, there is a presence of harmonics and sideband which indicate the crack in sample. Meanwhile, no occurrence of harmonics and sideband in uncrack sample (Guili et al., 2012).

There is a study of performance of patch repair between composite and metallic patches of crack aluminium plates under fatigue loading. Therefore, each type of patch will be conducted through fatigue test and the growth of crack behaviour will be analysed. The result show that the fatigue life of aluminium plate when patches with metal material lower than composite patches; even though metallic patches are weaker than composite (Saeed and Abid). There is numerical tool to study the propagation of fatigue crack in aluminium plates when repaired it with composite patch. The tool involve is finite element analysis and ABAQUS software. Through this method, parameter such as stress intensity factor can be determined (Maligno et al., 2013).

In studies of turbine blade application, in monitoring condition, parameter of natural frequencies should be considered. This is essential to determine the conditions and fatigue life time of blade turbine (Lecheb et al., 2013).

2.3 Method to Detect Fatigue Crack

The development of structural health monitoring (SHM) increasing in demand of accurate fatigue crack detection. This include the method of elastic wave.The initiation of fatigue crack of shell structure can be detected through the propagation of elastic wave. The detection of fatigue crack normally being observed near the hole. The analysis of this technique is based on frequency domain and time (Stawiarski et al., 2016).

A nonlinear acoustics method of damage detection involve classical and non-classical type. The non-classical type consist of propagation of elastic wave and wave interaction with damage. It has a good sensitivity and also can applied to undamaged structures, structural damage and structural joints. Example of phenomena of nonlinear vibration is open and closes of crack under dynamic loading (Pieczonka et al., 2016).

Next, the technique of laser ultrasonic is applied through propagation of Rayleigh wave in aluminium crack plate inspection. As result, higher number of components with low frequency will be obtained as the increasing crack depth. So, the characteristic of fatigue crack is depend on the changes in signal amplitude and centre frequency (Zhao et al., 2013).

Eddy current is an electromagnetic technique which can also be use in crack detection. This technique can be applied to weld metal such as steel bridges which can go through the conductive and paint coatings. Basically, eddy current can be as method of bridge inspection (Ichinose et al., 2007).

(Caizzone and DiGiampaolo, 2015) states that "In demand of using rapid tools in tracking structural damage; there is an increasing of using structural health monitoring (SHM) system. There were three type of category involve in this system. First, regarding the coupling of some local sensors and structural elements which include accelerometer, ultrasonic devices and fiber optics. Second, regarding on bringing instrumentation to demand of measurement site which consists of laser scanning, X-ray and infrared thermography. Lastly, based on the long distance of sensor to infrastructure site include the techniques of photogrammetry and

interferometry. But, there are improvement of SHM systems that categorized in two groups regarding the in-situ monitoring techniques. This includes wired and wireless group. The wired group has great resolution and it is precise. However, there are a few lack found because of high cost, longer time of installation and complicated. In comparison, wireless group is a fast and easy installation. There were divided into active and passive technique. Active technique used battery powered and can be use in transmission of long distances. But, it is expensive and lifespan is limited that depend on the battery usage. Meanwhile, in passive technique, use environment as energy source and also during the wireless communication, powered read out unit is collected. It can be obtained with low cost and chipless; as example the RFID sensor. It is used in identification of enlargement crack through wireless technique."

The fatigue crack in aerospace structure application can be detected by using an optical technique; temperature sensitive paint (TSP) technology. The technology involve the temperature sensitivity and there is elimination of pressure sensitive as the dynamic fatigue increase. Electrodynamic transducer is used in this technology. The appearance of a crack can be the criterion of failure through this method (Banaszak et al.).

Another method to detect fatigue crack is through acoustic emission (AE). The fatigue crack will generate elastic wave by using a piezoelectric transducer that mounted on the surface. The amplitude of the wave modes differ in crack depth (Kin LEE et al., 2006). The effect of loading ratio is studied by using AE experiments which can be seen through the relationship of AE count rates and rates of crack growth (Keshtgar et al., 2013). In addition, the entropy of AE can also be used in determination

of fatigue crack behaviour. The entropy o AE is estimate through time domain. This way of detection is useful in using the AE signal's amplitude (Amiri et al., 2015).

Vibrothermography is a transmission of mechanical wave technology that useful in detecting the hidden crack. It is very quick method; the presence of crack can be detected less than one second due to the quick propagation of ultrasound wave. Thus, it does not affect the higher rising of temperature of structure compare to implusive thermography. This technology is sensitive and can be applied to any metal cracks such as vertical cracks. However, it is a high cost and not precise in determine the location of crack depth (Rimare et al., 2012).

In comparison of acoustic emission (AE) and vibration technique on detection of bearing fault with three condition of different speeds. Result shows that AE signals will not present as the high frequency of above 50 kHz is involved. The AE signals has disadvantage where it has limitation on frequency. Thus, AE signals is not precise in diagnose small fault as the rotary speed slows down compare to the vibration techniques (Liu et al., 2011).

2.4 Vibro-acoustic Method

Vibroacoustic modulation (VAM) method is common used in crack detection where it is based on the low frequency vibration and high frequency acoustic wave. The sideband intensity correlated to the presence of damage. This study observing the Zhao-Atlas-Marks (ZAM) distribution in analysis of time-frequency. The result shows that the low frequency vibration modulate the amplitude of the sideband. Plus, the amplitude of sideband depend on the crack size (Trochidis et al., 2014).