Faculty of Mechanical Engineering

PREDICTING CRACK LOCATION IN PLATE USING NONLINEAR VIBRO-ACOUSTICS METHOD

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DECLARATION

I declare that this thesis entitled "Predicting Crack Location in Plate Using Nonlinear Vibro-Acoustics Method" is the result of my own work except cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : _____

Name : TAN KOK SIAN

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 Bachelor of Mechanical Engineering (with Honours).

Signature : _____

Name : PM DR. AZMA PUTRA

Date : _____

DEDICATION

To my beloved mother and father

ABSTRACT

The presence of damage such as a crack in a structure can be due to many reasons. The breakdown due to the presence of crack can arise in three (3) stages, namely the crack initiation, crack propagation and catastrophic overall failure. Therefore, a minor crack occurs in a very sensitive structure such as the aircraft which fails to be indicated or detected at the earlier stage can lead to a major failure in which can cause accident to happen. Hence, it is important to investigate the effect of natural frequency excitation in predicting the crack location in an aluminum plate using the nonlinear vibro-acoustics method as a model to the real scenario. The aluminum plate (AL-2024) with the size of (400mm x 150mm x 2mm) was used as the test specimen. The vibro-acoustics method is a method based on the fact that a high frequency ultrasonic wave propagates in the testing structure is modulated by the low frequency excitation. Besides that, the interaction between a high frequency vibration and a low frequency vibration results in nonlinear acoustic wave modulation. The nonlinear acoustic wave effects are closely related to the energy dissipation in materials or the nonlinear elasticity properties of the materials. Modal test analysis needs to be conducted to find the natural frequencies of the aluminum plate; the screening test and the Finite Element Analysis were applied to ensure the natural frequency obtained was correct. The low and high frequency waves were subjected simultaneously on the aluminum plate by using the mechanical shaker and PZT transducer respectively. The amplitude modulation intensity, R-values were used to determine the effectiveness of the frequency to predict the crack location in the aluminum plate. The knowledge of vibration mode shape needs to be used in order to predict the exact location of the crack in aluminum plate.

ABSTRAK

Terdapat pelbagai punca kepada berlakunya kerosakan seperti retak pada sesuatu struktur. Oleh itu, retakan kecil yang berlaku dalam struktur yang sangat sensitif seperti pesawat tidak dapat ditunjukkan atau dikesan pada peringkat awal, mampu mengakibatkan kerosakan besar yang boleh menyebabkan kemalangan berlaku. Oleh itu, adalah amat penting untuk mengkaji kesan pengujaan frekuensi semula jadi untuk mengesan lokasi retakan pada plat aluminium menggunakan kaedah vibro-akustik. Plat Aluminum (AL-2024) berukuran (400mm x 150mm x 2mm) digunakan sebagai bahan ujikaji. Kaedah vibro-akustik adalah suatu kaedah berdasarkan fakta yang menyatakan gelombang ultrasonik berfrekuensi tinggi dalam struktur ujian dimodulasi oleh pengujaan frekuensi yang rendah. Selain itu, hubungan interaksi antara getaran berfrekuensi tinggi dan getaran berfrekuensi rendah menghasilkan modulasi gelombang akustik secara tidak linear. Kesan gelombang akustik secara tidak linear ini berkait rapat dengan pelesapan tenaga dalam bahan atau sifat kekenyalan tidak linear bagi sesuatu bahan. Seterusnya, Analisis ujian modal perlu dilaksanakan untuk mengesan frekuensi semula jadi bagi plat aluminium dan dengan menggunakan ujian saringan dan Analisis Unsur Finite untuk memastikan dapatan kaji frekuensi semula jadi adalah tepat. Pengujaan frekuensi rendah dan gelombang frekuensi tinggi dikenakan secara serentak pada plat aluminum dengan menggunakan penggetar mekanikal dan transduser PZT secara asingan. Nilai R, intensiti modulasi amplitud digunakan untuk menentukan keberkesanan frekuensi dalam mengesan lokasi retakan pada plat aluminum. Pengetahuan mengenai bentuk mod getaran perlu diaplikasikan untuk mengesan lokasi tepat retakan pada plat aluminum.

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SHM	Structural Health Monitoring
NDT	Nondestructive Testing
VAM	Vibro-Acoustics Method
UTM	Universal Testing Machine
EDM	Electronic Discharge Machine
FEA	Finite Element Analysis
FE	Finite Element
PZT	Piezoelectric Transducer
FFT	Fast Fourier Transform
SLDV	Scanning Lase Doppler Vibrometer
BBA	Boardband Amplifier
S-N	Stress and Number of cycle
UT	Ultrasonic Testing
MT	Magnetic Particle Testing
AE	Acoustic Emission

LIST OF SYMBOL

R	=	Amplitude modulation intensity
A_0	=	Carrier peak amplitude
A_1	=	First sideband amplitude on the left of carrier peak amplitude
A_2	=	First sideband amplitude on the right of carrier peak amplitude
f_c	=	High frequency/frequency of carrier peak
f_m	=	Low excitation frequency

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Structural Health Monitoring (SHM) plays an important role in maintenance, especially in structural damage detection. In SHM, there are a series of processes and characterization strategies in the maintenance for engineering structure such as building structure, aircraft structure and pipeline structure. A series of processes in SHM involves the observation or inspection of a system by using sensor for a long period of time and also the statistical analysis of these features to determine the crack damage on the particular structure. Yu and Giurgiutiu (2009) said that, the structural crack or damage can be detected or diagnosed by using embedded sensing elements which collect the data all the time about the sensitive structural components. The data collected from the tested structure can be used for further analysis to detect the abnormality happened on the structure, especially in high sensitivity structure. The engineers can then take actions such as the maintenance or replacement of the component of the structure at the early stages to prevent catastrophic failure. The common damage is the change on the material and geometric properties of a structure which includes crack, hole, corrosion etc.

There are many method used in various fields of engineering to detect the damage in the structure such as the Nondestructive Testing (NDT) method. Previous study by Sutin et al (1998) claimed that the NDT method is a method that can measure or inspect the structure without destroying it and thus ensure the structure remains as it original shape and functionality. The NDT methods which can be used in the damage detection are nonlinear vibro-acoustic, radiography, ultrasonic testing, dye penetrate, magnetic particle, infrared thermography and acoustic emission. The selection of the testing method is dependent on the type of testing structure together with the operating conditions and the environment. For example, the infrared thermography method can only be used when the system is operating or in online state; this is because the method detects the abnormality based on the surface temperature of the testing object. Besides that, the nonlinear vibro-acoustic method is more preferable to carry out during the offline state as this method needs to introduce two different frequencies, one low excitation frequency and one high frequency vibration without any disturbance and noise.

1.2 PROBLEM STATEMENT

Minor failure occurs in sensitive structure which does not get detected in the earlier stage can lead to a catastrophic failure. When the whole system is breaking down, it requires extra breakdown maintenance fees to repair the failure. The worst possible scenario is that the production cycles have to come to a halt due to the failure and this causes a huge loss in production and thus reduces the productivity of the company. All these chaos end up with extra expenses needed to repair or to carry out great maintenance work. In short, it is much more affordable to prevent it from becoming a problem in the first place.

The common damage on a structure is fatigue crack. From the previous study by the Robert Stone (1983) about the steel materials, the materials possess a threshold stress limit below which fatigue cracks will not initiate. This threshold stress value is often referred to as the endurance limit. In steels, the life associated with this behavior is generally accepted to be 2 x 106 cycles. In the other words, if a given stress state does not induce a fatigue failure within the first 2 x 106 cycles, future failure of the component is considered unlikely.

Fatigue crack present in a structure can due to various reasons. A small crack in a very sensitive structure can lead to catastrophic failure. For example, presence of a small crack in the body of aircraft can cause accident to happen. Besides that, presence of a small crack in a pipeline system can lead to explosion of the pipeline and affect the people surround it. Thus, the non-linear vibro-acoustic method (VAM) can be used to detect the crack by introducing two (2) frequencies, one is the low frequency excitation and the other one is the high frequency vibration. However, it requires both the vibro-acoustic method (VAM) and also the knowledge of vibration mode shape to predict the exact location of the crack in a structure. Plus, there are not much of studies in predicting the location of the crack in a structure. Hence, this study is carried out to predict the crack location in an aluminum plate by using the VAM.

1.3 OBJECTIVE

1. To investigate the effect of the vibration mode shape on crack detection.
2. To predict the crack location in aluminum plate by using the non-linear vibro-acoustic method (VAM).

1.4 SCOPE

The scope of this study is about the prediction of the crack location of an aluminum plate with the size of (400mm X 150mm). The preparation of the aluminum plate specimens of the same size is important to obtain the highest accuracy possible of the experimental results. After that, three (3) different fatigue crack locations which are the middle, above middle and edge are prepared at three (3) different aluminum plates by using the Instron Universal Testing Machine (UTM). Before using the UTM to prepare the fatigue crack, a notch (5.0 mm) to initiate the fatigue crack is prepared by using the Electronic Discharge Machine (EDM).

The range of the natural frequency of the specimen was obtained by using the Finite Element Analysis (FEA) simulation. However, the usual procedure was to test the first specimen with random frequency to obtain the natural frequency of the specimen in the experiment. This process was known as the modal test analysis, which was to obtain the exact value of natural frequency of the specimen and to confirm it by using the screening test simulation. The specimen was then excited at its natural frequency, which was a low frequency excitation, and simultaneously provided with a high frequency vibration by the PZT transducer to obtain the amplitude of vibration occurring at the every position in the plate.

After that, the data was obtained by using several types of transducer for further analysis. The time domain spectrum was transformed by using the Fast Fourier Transform (FFT) in Matlab into the frequency domain spectrum for further analysis on the crack location. The frequency domain spectrum provides the information of side band around the carrier peak frequency that allows the user to obtain the R-value and compare with the vibration mode shape to determine the crack location in the aluminum plate.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Literature review is an objective, critical summary of published research literature relevant to a topic under consideration research. In literature review, studies related to the crack detection are reviewed as they provide information closely related to the topic. Information such as cause and mode of the vibration, fatigue failure, frequency domain approach, vibro-acoustic method, and experiment procedure to be used can be obtained through literature review. Literature review also shows the potential weakness and strength of this study and an up-to-date understanding of the subject. The purpose of literature review is to create familiarity with current thinking and research on a particular topic, and may justify future research into a previously overlooked or understudied area. The most important reason of doing literature review is to identify the problem in the study and give an overall view of the title to ensure falling on the right track for this study. The information from articles, journals or references books could help to understand and gather the ideas to proceed with this study. Hence, a complete literature review must be included to accomplish the title in this study.

2.2 DAMAGE IN STRUCTURE

According to the Budynas et al (2014), generally, damage can be defined as any change occur or subject into a system that affects the performance of the system from its original functionality. The concept of the damage would be clearer if there is a comparison between the damaged and undamaged system or structure. Therefore, with comparison it shows the original function of the particular system and the structure. Since this study focuses on the crack occur or detection on the structure, so it is limited to the changes occur to the structural geometric or material. For example, a crack or damage occurs in the structure will alter the geometric and change the properties of the structure such as strength or stiffness of the structure. Hence, the primary function of the structure will be altered and changed; break down of the structure might occur if the intensity of the damage intensity increased. The result of the present damage in the structure might cause immediate effect on the overall system, it depends on the severity of the damage and also the position of the damage in the structure (Sohn et al., 2003).

Based on the previous study by Qiao et al (2012) claimed that there are many reasons to cause damage in a structural system, such as corrosion, thermal affects, earthquakes and overloads towards a structural system. The risk of damage in a structural system, for example a crack on an aircraft due to scheduled discrete of landing purpose will result in accidents such as aircraft break downs and crashes. Furthermore, unscheduled discrete such as natural disaster earthquake will cause the structure of the building to break down and the whole building will collapse (Sohn et al., 2003). However, a reliable method on the detection of the crack and prediction of the crack location on a structure at the early stage is very important to prevent the catastrophic failure from occurrence. Besides that, it can reduce the cost of maintenance if the damage or crack is found at the earlier stage (Alberto et al., 2004).