FATIGUE CRACK DETECTION IN ALUMINIUM PIPE BY USING NON-LINEAR VIBRO ACOUSTIC METHOD

HOOI MAN POH

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

FATIGUE CRACK DETECTION IN ALUMINIUM PIPE BY USING NON-LINEAR VIBRO ACOUSTIC METHOD

HOOI MAN POH

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DECLARATION

I declare that this project report entitled "Fatigue Crack Detection In Aluminium Pipe By Using Non-Linear Vibro Acoustic Method" is the result of my own work except as cited in the references

Signature : ....

Name : ....

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

Signature :. ....

Name of Supervisor : ....

Date : ....

DEDICATION

To my beloved mother and father

ABSTRACT

Fatigue crack presence is the most common structural failure and there are several factors to cause fatigue crack. In this research non-linear vibro acoustic method has been introduced for the crack detection on aluminium pipe. Non-linear vibro acoustic approach is the most appropriate method for detecting the existence of fatigue crack as it is very sensitive even to a very tiny damage severity. The nonlinear vibro-acoustic modulation is a technique which combined the intensive low frequency (modal) excitation and high frequency ultrasonic wave. Several procedures have been taken for this project including the preparation of the test specimen, the modal analysis test and the vibro-acoustic test. The test specimen used in this experiment is a 102.3mm x 114.3mm x 1000mm aluminium pipe (Al-6061). A slot size with dimension 10mm x 2mm was created by using milling machine on test specimen. The test specimen undergoes modal test analysis to determine the resonant frequencies and followed by the vibro-acoustic method. Data from modal analysis is applied in vibro-acoustic test as low frequency excitation with 60kHz high ultrasonic wave. The vibro-acoustic test used is to accomplish the goal of performing the non-linear vibro acoustic test at aluminium pipe with different slot size in detecting the fatigue crack. Modulation intensity (R-value) is obtained by calculation and related to effect of the size dimension.

ABSTRAK

Kehadiran retak adalah kegagalan struktur yang paling biasa dan terdapat beberapa faktor untuk menyebabkan retak. Dalam penyelidikan ini, kaedah akustik yang tidak linear telah diperkenalkan bagi mengesan retak pada paip aluminium. Pendekatan akustik non-linear adalah kaedah yang paling sesuai untuk mengesan kewujudan retak kerana ia adalah sangat sensitif walaupun dengan keterukan kerosakan yang sangat kecil. Modin akustik bukan linear adalah satu teknik yang menggabungkan frekuensi rendah (mod) yang intensif dan gelombang ultrasonik frekuensi tinggi. Beberapa prosedur telah diambil untuk projek ini termasuk penyediaan spesimen ujian, ujian analisis mod dan ujian getaran-akustik. Spesimen ujian yang digunakan dalam percubaan ini ialah paip aluminium 102.3 mm x 114.3 mm x 1000mm (Al-6061). Saiz slot dengan dimensi 10mm x 2mm telah dicipta dengan menggunakan Mesin pengilangan pada spesimen ujian. Spesimen ujian mengalami analisis ujian mod untuk menentukan frekuensi resonant dan diikuti dengan kaedah getaran-akustik. Data dari analisis mod digunakan dalam ujian geto-akustik sebagai frekuensi rendah berdetik dengan gelombang ultrasonik 60kHz yang tinggi. Ujian getaran-akustik yang digunakan adalah untuk mencapai matlamat melaksanakan ujian akustik non-linear getaran pada paip aluminium dengan saiz slot yang berbeza dalam mengesan kelesuan retak. Intensiti nilai (Nilai-R) diperolehi melalui pengiraan dan berkaitan dengan kesan dimensi saiz.

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LIST OF ABBEREVATIONS

DAC	Digital to Analog Converter
DDS	Direct Digital Synthesis
ED	Electrodynamic
FEA	Finite Element Analysis
FRF	Frequency Response Function
HF	High Frequency
LF	Low Frequency
PSB	Persistent Slip Bands
SHM	Structural Health Monitoring
SLDV	Scanning Laser Doppler Vibrometer
VAM	Vibro-Acoustic Modulation

CHAPTER 1

INTRODUCTION

1.1 Background

Structural Health Monitoring (SHM) is the method of introducing a plan to track damage to structural (Farrar and Worden, 2007). Damage identification is performed along with five closely related fields of study including SHM, condition monitoring, non-destructive evaluation, statistical process control, and prognosis of damage.

Vibro-acoustic modulation (VAM) is an example of non-destructive research method used for identification of defects in nonlinear acoustic methods. The VAM comprises twin-frequency sine wave and a analysis of the correlation of this wave with the inherent faults. The existing research on the dynamics of VAM for a standard material body is described in this thesis. The responsibilities of various types of defects on the response of the material are examined. The conceptual study reveals the origin of nonlinear frequencies in the face of rising resonances and sidebands that are frequently found in the VAM output response.

VAM is a concept that focuses on the frequency modulation impact on a not significant high frequency probing wave by a low frequency pumping vibration that happens in fundamental vibrational modes. Due to the modulation effect, the sideband spectral elements around the principal high frequency peak are produced within the fourier series structure when the control structure is concurrently excited by all of these signals. This behaviour is unnoticeable and the spectra of responses will superpose the responses to each specific signal if the structure is undamaged. The modulation effect is easily detectable as the system is slotted and seems to be nonlinear.

Apart from this, the study gives observations into the interactions between the magnitude of nonlinear responses and the magnitudes of input vibrations and the physical sources of nonlinear responses. A finite element analysis of VAM is also conducted for a physical visualisation of the nonlinear vibrations affiliated with the theory. The model explores the scientific validity of applying VAM to map damage in physical structures. The prototype is also applied to further investigate the defect size and depth of the VAM nonlinear mechanism.

1.2 Problem Statement

The occurrence of fatigue crack is the most common structural defect. There are several factors causes fatigue cracks exist in the structures. The existence of cracks can affect a local variation and can have a significant impact on the mechanical behaviour of the whole system. Consequently, a non-linear vibro acoustic approach is particularly suitable for identifying the occurrence of fatigue crack since it is very resilient to only a limited degree of defect and this technique need not involve dense sensor networks. Nonetheless, there are no extensive investigation have been performed to analyse the influence of different slot dimensions on the sensitivity to non-linear effects, so this research is performed using vibro acoustic method to identify fatigue crack.

1.3 Objectives

The objectives of this project are as follow :

1. To perform the non-linear vibro acoustic test at aluminium pipe with different slot size in detecting the fatigue crack.
2. To determine the relationship between the slot size and the effect of fatigue crack.

1.4 Scope of Project

In this project, the scopes need to cover include:

a. Preparation of the test specimen slot with dimension 10mm length , 2mm width and 0 – 6 mm depth by using milling machine.
b. Perform non-linear vibro acoustic test on test specimen (aluminium pipe) to obtain mode shapes and resonant frequencies by using modal test.
c. Determine the relation between the slot sizes with modulation effect.
d. Analysis of the experimental data to obtain the non-linear wave modulation effect

CHAPTER 2

LITERATURE REVIEW

2.1 Damage in Structure

There are a lot of different methods have been established to identify the defect in the structures. Damage usually defined as shift in the system that will affects its performance. Damage was also defined as changes in structural on the material or geometric properties of a mechanical or structural system (Sohn *et al.*, 2004). Besides that, in the view of mechanical damage in solid materials was known as the growth and creation of microcracks or microvoids which will create discontinuities in a medium (Lemaitre and Desmorat, 2005). One of the major damage mechanisms in structural materials is fatigue cracking as shown in Figure 2.1. Normally fatigue cracking happened in structure when cyclic stresses are lower than the ultimate tensile stress or even material yield stress. A component's fatigue life can be defined as the number of loading cycles required to trigger a fatigue crack and propagate the crack to critical size (*Fatigue Properties,* no date). Hence, there are three stages fatigue failure occurs - crack initiation which are slow, stable crack growth and rapid fracture. Dislocations is an important part in the initiation phase of fatigue crack. Persistent slip bands (PSB) was the accumulation of dislocations on the surface near to stress concentrations area after a huge number of loading cycles in the first stage. While in the second stage of fatigue, combination of the tiny microcracks growth and spread along the material toward the maximum tensile stress in the direction with 90º. Continuity growth of cracks until the uncracked compound of the components is no longer supported by continuous cyclic loading.

The third stage of fatigue failure occurred when the fracture strength was exceeded and the remaining cross-section of the material experienced rapid fracture (*Fatigue Properties*, no date).

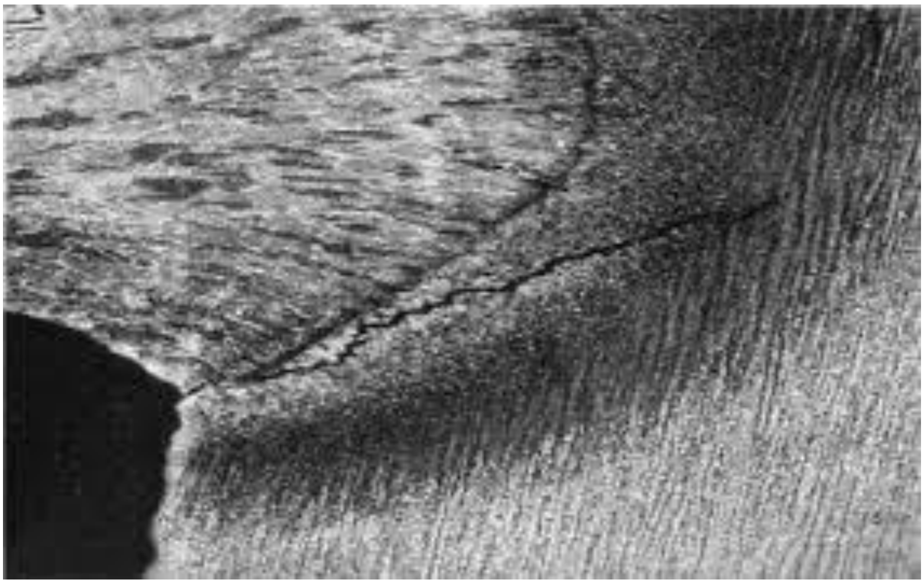

Figure 2. 1 : Fatigue crack in structure

2.2 Modal Test

Modal analysis is an essential technique to describe the vibration behaviours of mechanical structures. It transforms the excitation dynamic response and measured responses to a complicated system that is hard to interpret into a series of modal parameters that can be easy to predict. The application of modal analysis is helpful in data obtaining and visualization techniques. Modal analysis often transmit a complicated system which is hard to observe in a series of separable only degree systems of independance that are easily to identify. Besides that, the modal analysis is used to define resonant frequency, modal damping and mode shapes of a structure with reference to FRF measurements (*Basics of Modal Testing and Analysis*, 2016). Mode shapes and natural frequencies able to forecast by applying statistical method named Finite Element Analysis (FEA) models, which are named the modal parameters for short. Modal analysis is an essential tool to identify and resolve problems related to structural vibration. When an excitation mechanism interacts with the structure's natural frequency, a common vibration problem that can be detected with modal analysis occurs. In order to identify its frequency components, the excitation function can be analysed in the frequency domain. When the excitation frequency overlaps with the structure's natural frequency, the structure can display very high vibration levels that can cause to fatigue and failure of the structure. The structure's natural frequencies, coefficients of damping, and mode shapes can be determine in modal analysis. The arrangement may be adjusted or updated to alter the frequency response apart from the vibration response as it is determined that the intensity of vibration corresponds to another of the natural frequencies used in the modal analysis.

Measurement of the excitation and response of the structure under experiment is the initial action in experimental modal analysis. The system must be excited and both the excitation force applied and the resulting vibrations of response, generally accelerations, are measured resulting in a set of data for the Frequency Response Function. The modal parameters can be determined by using the FRF data set which comprising natural frequencies, damping coefficients, and mode shapes (Daniel J.Inman, 2001). Data can be then animated visually when the mode shaper. To have the vibrating reactions, the system needs to be excited. Two general methods of excitation normally used in experiment are impact hammer and modal shaker. The hammer is equipped with a testing machine that produces an electrical signal proportional to the toggle force whereby the maximum force is determined when the experiment is carried out. Typically, modal analysis on simple structures uses impact hammer or it is not feasible to add a modal shaker. With the hammer, various hardness impact tips can be used to change the impact frequency range of the measurement. If measurements of low frequency are desired, a soft rubber tip could be applied, and a hard metal tip could be applied if measurements of high frequency are desired.

A modal shaker is usually applied for laboratory modal test measurements. Modal shaker are different in size as they are rated by the force produced by them. The driving forces acquired by the shaker is the key for choosing the modal shaker size to make sure enough level of response on the structure during experiment. To test the excitation force, a impact device is mounted at the operation position on the structure and attached to another side of the stinger. A shaker is often powered by the DAC (digital to analog converter) of the dynamic signal analyzer, an electronic device which produces carefully tuned electronic signals that are then magnified and transformed into the excitation signals. The structure can be excited by multiple types of excitation signal profiles.

The next step is to determine the excitation and also the responses once the mechanism is excited. This is usually performed by using a Dynamic Signal Analyzer to position force sensor and accelerometers on the system and record the response of force and acceleration. Conversion of electronic signal into acceleration and measurement on it have been performed by an electronic sensor which called accelerometer (*Basics of Modal Testing and Analysis*, 2016). Two types of accelerometer are available which are uniaxial and tri-axial accelerometers. In addition, a tri-axial accelerometer is combination of three accelerometers together, positioned right angle to everyone to ensure the measurement of vibration across 3 axes. An instrument called the Dynamic Signal Analyzer used for measuring and capturing signals and processing those signals to the frequency domain data.

Frequency Response Functions (FRFs) and Coherence are the common kinds of signals applied in modal analysis. Frequency Response Function (FRF) is derived through two signals which called response (output) and excitation (input) and also known as “transfer function”. The FRF represents the ratio of one signal over the appropriate frequency range with respect to another signal.

Normally, this is applied in a modal analysis where the pulse power of the mechanism is evaluated on the basis of impact stimulation from the hammer or modal shaker. Coherence is connected to the FRF and informs what section of the response to the excitation is attributed. This is a frequency function which do shift from null to one (Daniel J.Inman, 2001). To evaluate the quality of a measurement, the signal is applied in modal analysis. Nonetheless, it is common for consistency to be low in an anti-resonance or structural nodes with very low vibration responses. One block of time data have been used usually for calculating frequency domain data. Some irregular noise that could distort true resonant frequencies and mode shapes has been covered in every block of time data. Uncorrelated random noise will be minimized by averaging a few blocks of data. The advantage of averaging is that it minimizes the impact of random noise and results in smoother data.

2.3 Vibro-acoustic Method

Non-linear vibro-acoustics have been used for detecting crack in solids for many years. The approach uses a variety of nonlinear phenomena correlated with surface imperfections and thermo-elastic actions of interfaces. Hence, it is specifically for detecting crack in metallic structures (Hu *et al.*, 2010). The nonlinear vibro-acoustic modulation is a methodology that mixes extreme low-frequency (modal) signal with high-frequency ultrasonic pulse. Such two excitations are concurrently added to the structure as shown in Figure 2.2 (Klepka *et al.*, 2014). The prevailing opinion of all these studies is that nonlinear crack effects are greater than crack-induced variations found in standard linear characteristics (Klepka *et al.*, 2012). When supervised structures are untouched or undamaged, only the two main frequency components corresponding to the propagating ultrasonic wave and low frequency excitation are demonstrated in the signal response spectra as illustrated in Figure 2.3. As shown by the Figure 2.4, when the monitored components are disrupted, the response signals spectra include additional sidebands around the ultrasonic core portion (Klepka *et al.*, 2014).

The modulation intensity was tracked by using the parameter R defined as

$$R = \frac{A_1 + A_2}{A_0}$$

Where A_0 is the spectral amplitude of the carrier acoustical frequency, A_1 and A_2 are the spectral amplitudes of the first pair of sidebands.

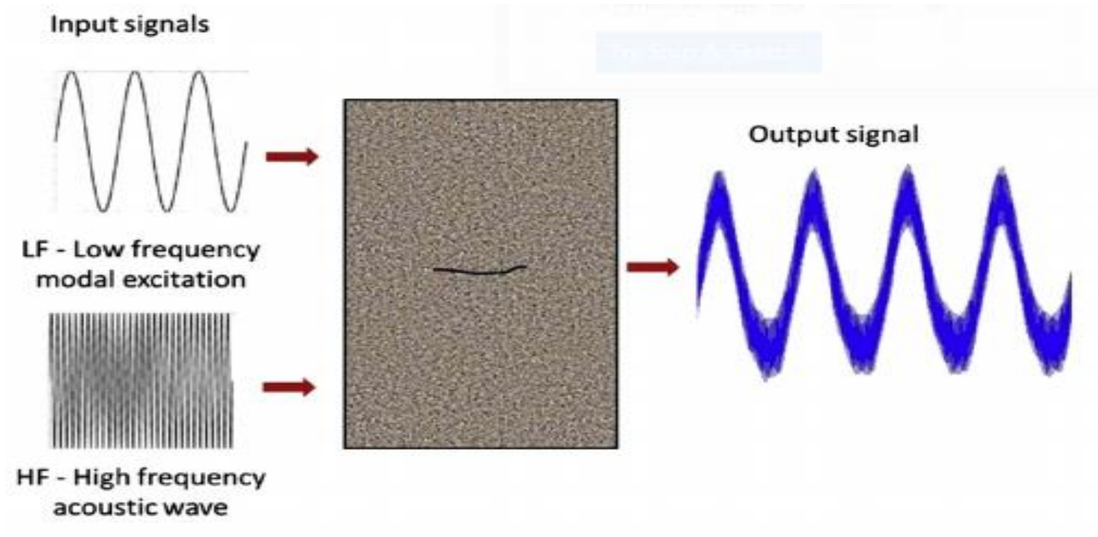

Figure 2. 2 : The principle of nonlinear vibro-acoustic wave modulation technique: schematic diagram illustrating the method.

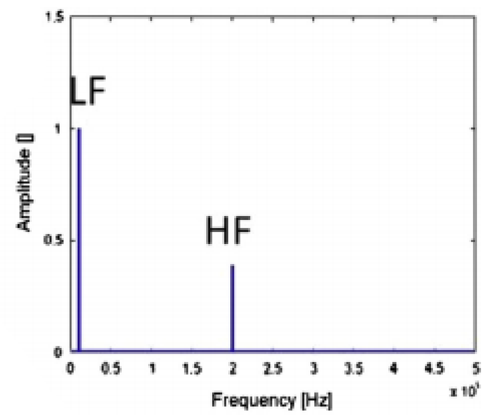

Figure 2. 3 : Power spectrum of response signal for undamaged structure.