EFFECT OF WAVE MODULATION MEASURED AT VARIOUS LOCATIONS FOR DAMAGE DETECTION USING VIBRO ACOUSTIC METHOD

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EFFECT OF WAVE MODULATION MEASURED AT VARIOUS LOCATIONS FOR DAMAGE DETECTION USING VIBRO-ACOUSTIC METHOD

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DECLARATION

I declare that this project report entitled “Effect Of Wave Modulation Measured At Various Locations For Damage Detection Using 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 (Plant & Maintenance).

Signature :. ....

Name of Supervisor : ....

Date : ....

DEDICATION

To my beloved mother and father

ABSTRACT

Structural Health Monitoring has greatly developed in recent years where more advanced method was studied and applied practically in our daily lives. Among the most commonly applied in the method is the nonlinear acoustic effect excite simultaneously with low frequency. This application has been researched to determine the reliability to detect fatigue crack in specimen. In general, every material in this world is restricted to certain period of life span. There are 3 stages of fatigue failure development from the initiation of micro crack up to the fracture of the material. Crack formation is then classified into 3 modes where the mode is depends on the manner force applied on the plate. The fatigue crack propagation does not increase proportional with the number of load cycles. An aluminum plate is prepared into the required specification in order to proceed with the vibro-acoustic test. The natural frequency is determined through modal analysis and then the mode shape was confirmed using the VL scanning software. Then the first 3 mode shape frequency was excited for the vibro-acoustic analysis where the location of measurement was distributed into 25 points above the crack line. Based the modulation intensity (R-value) at each points, an analysis was done on the graph of R-value against measurement point distance from crack. Lastly, a contour plot was produced to ease the understanding on modulation intensity distribution on the measurement points for all 3 modes.

ABSTRAK

Pemantauan kesihatan strucktur telah kian maju dimana semakin banyak kaedah canggih dikaji dan dipraktikkan dalam kehidupan seharian. Antara kaedah-kaedah yang lazim digunakan adalah kesan akustik tidak linear yang dirangsang serentak dengan frekuansi rendah. Penggunaan kaedah telah dikaji keandalannya untuk mengesan retak lesu dalam spesimen. Secara amnya, setiap bahan dalam dunia ini mempunyai jangka hayat yang tertentu. Terdapat 3 peringkat retak lesu yang bermula dengan retak mikro sehingga fraktur. Formasi retak ini dibahagi kepada 3 mod bergantung pada cara daya tekanan yang diaplikasi pada plat. Perkembangan retak lesu ini tidak meningkat secara linear dengan bilangan kitaran daya tekanan. Sekeping play aluminum disediakan mengikut spesifikasi tertentu dan dilanjutkan dengan kajian vibro akustik. Frekuansi resonan ditentukan melalui analisis modal dan bentuk mod menggunakan perisai pengimbasan VL. 3 frekuansi mod pertama dirangsang untuk analisis vibro akustik di mana lokasi pengukuran dibahagi kepada 25 titik di atas garis retakan. Analisis dijalankan melalui bandingan intensis modulasi (R-value) di 25 titik dan graf diplot R-value berbanding jarak lokasi pengukuran dari garis retakan. Akhir sekali, plot kontur diplot untuk memudahkan perbandingan dan pemahaman intensiti modulasi pada lokasi pengukuran untuk ketiga-tiga frekuansi mod.

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LIST OF ABBREVIATIONS

SHM	Structure Health Monitoring
NDT	Non-Destructive Test
NDE	Non-Destructive Evaluation
PZT	Piezoelectric Transducer

CHAPTER 1

INTRODUCTION

1.1 Background

In the 21st century, diagnosis and early evaluation on the degree of structure damage has become more crucial. The most general approach of this task is Structural Health Monitoring (SHM) in order to sustain the safety, reliability and performance of the structure. This application is extensively used in various type of structure such as aircraft, bridges and buildings. SHM is a non-destructive scientific process of identifying four characteristics real-time or near real-time related to fitness of an engineered system as it operates using a built-in sensory and reasoner system. The four characteristics are [1]:

a. Operational and environmental loads acting on a component
b. Mechanical damage caused by the load
c. Growth of damage as the component operates
d. Future performance of the component as damage accumulates.

In such, there are several advanced non-destructive test/evaluation (NDT/NDE) widely used in various engineering fields to fulfil the definition. In 2004, there are several NDT techniques that have been summarized [2] [3].

Dye penetration where a liquid or penetrant such as chalk is applied on a cleaned and low roughness material surface. Then the penetrant will infiltrates the surface’s flaw which will reveal the place where penetrant crept in. This characteristic makes it possible to detect a micro crack which is only 0.00005 mm wide.

Magnetic particle method uses the principle that a flaw in magnetic material produces distortion in an induced magnetic field. This is a simple and most sensitive method in NDT to apply even along complex geometries. Due to the fact that this method can be applied on a very large surface of component at once, it has a very high potential to be fully automated and production line integrated [4].

Eddy-current testing is a method which based on physics phenomenon of electromagnetic induction. A probe that consists of a wire coil and generated oscillating magnetic field is brought close to a conductive material such as metal piece. Then a circular flow of electrons or better known as eddy current will begin to move across the metal and will generate its own magnetic field which interacts with the coil. Any changes in the thickness or defect along the surface cracking will affect the amplitude and pattern of the eddy current and the magnetic field [5].

Ultrasound method transmits an ultrasonic wave into a test material and any defects in the material will reflect a pulse wave and the reflected waves are measured. Then the waves will be digitized leads to a change of the echo shape in comparison with an analogue display. This enable a better visualisation on defect which is only hit by one ultrasonic shot [6]. However, it is very tough to distinguish between cracks and other types of defect where it has a limited application toward specific specimen geometry.

Along with the advancement of technology, improvement in NDT methods allows mankind to use better sensor, material technology, new analysis tools and software for better damage detection or structural health monitoring. Among these advanced methods is guided wave inspection, infrared thermography, acoustic and etc..

Guided wave has been applied in solids such as seismology, inspection, material characterisation, delay lines and etc. [7]. Among the main class of these waves is Lamb waves and Rayleigh wave which is dispersive plate wave and surface wave respectively.

These waves can propagate in any solid structure which has boundaries as it is essential element for guided waves. Guided waves are a group of waves at which various modes is in superposition. The phenomenon is due to the stress and strain condition of the boundaries [8].

Infrared thermography is another approach of advanced NDT for damage detection which is fast, non-contact and able to cover a wide area of inspection in compared with the conventional NDE techniques. Basically any object above the absolute zero temperature will emit infrared radiation which makes this method so useful. There are two general approaches which is passive, where the feature of interest is naturally contrast temperature than the background. The active approach is where an energy source is required to produce thermal contrast between the feature of interest and the background. Generally, most of the cases will apply the active approach as the feature of interest temperature is normally in equilibrium with the surrounding. Then in the active approach it is divided into external, energy is transfer to the surface and then propagated through the material until a flaw is encountered. It is commonly performed with optical devices such as photographic flashed or halogen lamps. Other than that is internal active approach, where energy is injected into the material to stimulate exclusively the defects. The energy is normally excites by using mechanical oscillations like sonic or ultrasonic transducer. A summary of infrared thermography approaches is as in Figure 1-1 [9].

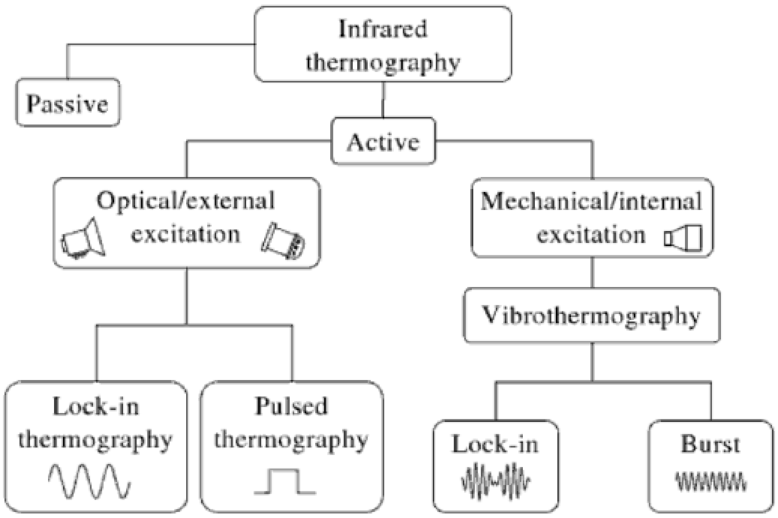

Figure 1-1: Approaches of Infrared Thermography

1.2 Problem Statement

Vibro-acoustic is one of the methods to determine the fatigue crack which uses the propagation of high frequency acoustic waves in solid structure with low frequency excitation. Therefore, several parameters should be considered in order to obtain an effective result. Among the parameters are:

a) Low frequency excitation location and frequency

b) High frequency excitation location and frequency

c) Location of measurement point

1.3 Objectives

There are several parameters which will affect the wave modulation of the experiment. However, this study would focus on the effect of the measurement point location towards the wave modulation effect from low and high frequencies excite to detect the crack.

1.4 Scope of Project

The scopes of this project are:

1. Sample preparation which consists of 4 procedures in order to begin the experiment which is:
   - Cutting a piece of aluminum plate to the required dimension.
   - Drilling hole to allow line cutting
   - Line cutting in order to initiate fatigue crack
   - Create fatigue crack
2. Modal analysis to determine the aluminum plate vibration modes
   - Sweep frequency excitation to determine the natural frequency
   - VL scanning software to determine the relevant mode shape.
   - Obtain the first 3 modes shape.
3. Non-linear vibro-acoustic test to determine effect of various measurement points towards the modulation intensity in fatigue crack detection.
   - Distribute 25 measurement points above the crack which is 30 mm apart each point.
   - Analyse R-value based on 1st sideband analysis, 2nd sideband analysis and 1st + 2nd sideband analysis.

Analyse contour plot of individual R-value on the aluminum plate.

CHAPTER 2

LITERATURE REVIEW

2.1 Damage in structure

Structure is defined as the system for transferring of loads from one place to another [10]. Damage can be defined as the deviation in structure from its original geometric or material properties that caused by unacceptable stress, displacement or vibration in the structure [11]. There are two most common mode of degradation and failure is due to the localised phenomena such as crack propagation at reduced cross sections. One of the mode would have lesser noticeable degradation in the initial cycles and the once the degradation occurs it would happen with a very fast rate. This will show the degradation process covering only a very small portion of the material life-span. Then another mode the degradation threshold is very small where the degradation occurs at a slower rate with the number of cycles. Based on the flow, it would cover up a larger portion of degradation in the life-span of the material. The summarised modes of degradation are as in Figure 2-1 [12].

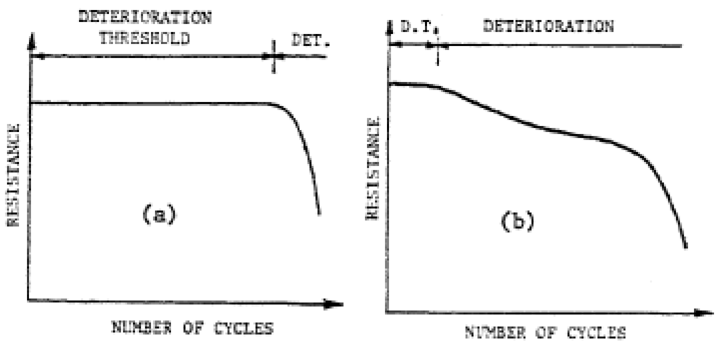

Figure 2-1 Modes of degradation

Among the damage in structure, the most commonly discussed is the damage initiation in fatigue behaviour of a material. The damage due to fatigue is hard to be identify because the nucleation damage in pristine can be large part of the total fatigue life. Not only that, for every different material the crack dimension might vary from a microscopic scales up to few millimetres depending on the structure and application [13].

2.2 Fatigue crack

Fatigue failure is defined as the failures due to stresses repeating for a larger number of times. Basically it consists of three stages for the fatigue failure development starting with stage 1 where the initiation of micro cracks due to cyclic plastic deformation. However, at this stage of process it is not visible to naked eyes where people overlooked. Then it followed with stage 2 where propagation of micro crack to macro cracks forming parallel plate like fracture surfaces separated by longitudinal ridges. This is the stage where users begin to realise the development before it fracture. Lastly is stage 3, the fracture stage where the material could not support the loads any longer. All the process is picturised as in Figure 2-2 [14].

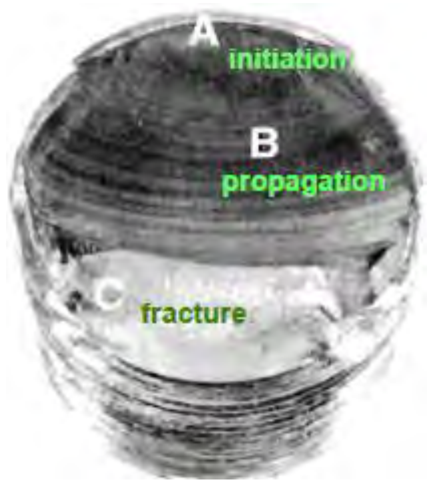

Figure 2-2: Stages of fatigue failure development

Crack formation on the plate can be distinguish in several manner based on the force applied on the plate. Mode I is the opening mode where the body of material is loaded by tensile forces such that it is pulled apart in the y-axis. Mode II, the sliding mode where material body is loaded by shear forces that is parallel to the crack surface in the x-axis. Mode III is tearing mode where the body is loaded with shear forces parallel to the crack front the crack surface. However, in some cases all the three modes might happen in a mixed situation or can be called as superposition situation. Combination of the 3 modes can be illustrated as in Figure 2-3 [15].

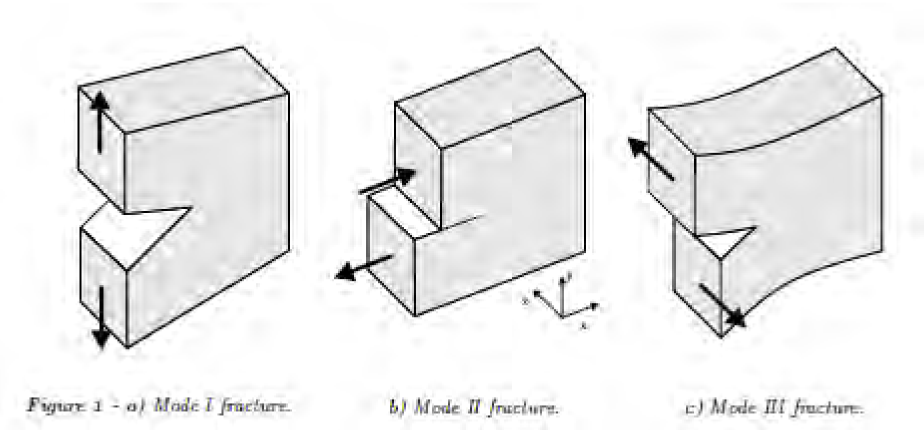

Figure 2-3: Three basic modes of fatigue crack in plate

Once the fatigue crack is present in the material, the crack propagation is noticeable that in such crack length increases with number of loading cycles. It could also be seen that the crack growth rate would increase with the increasing crack length. Then the growth rate of the crack increases with the developing stress level. The crack process becomes longer with a rapid rate where the crack does not increase linearly with the number of loading cycles. However, lots of the loading cycles concerned in the complete life of the component are consumed during the early levels of the crack extension. The summary of the elemental parameters of the fatigue crack growth is as in Figure 2-4 [16].

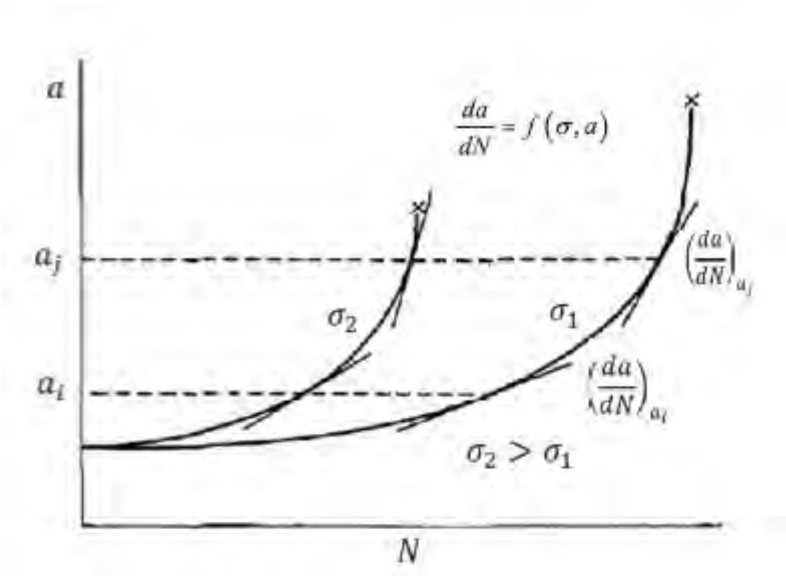

Figure 2-4: Effect of crack length and stress level on crack propagation rate

2.3 Methods to detect fatigue crack

2.3.1 Nonlinear Acoustics

In up to date years, nonlinear effect from acoustic wave has been widely studied in order to detect damage [17, 18]. This is because the method allowed early detection on micro damage and it is easier to detect in compared with the traditional linear measurement [19, 20]. There are several common nonlinear effects that strongly dependant on the wave propagating medium such as generation of side bands, amplitude dissipation, generation of harmonics and resonant waves shifting. Nonlinear effects for instance amplitude modulation is commonly known as interaction of the wave with micro-inhomogeneous medium [21]. Therefore it has been a common finding in most of the studies on nonlinear effect that correlated with defects such as discontinuities present in the medium.

Back in the 1970s, nonlinear acoustics has been thoroughly studies by Rudenko, Zaitsev and many others. There are lots of reports on the nonlinear effect of elastic wave propagation in metals, polymers and soils being used to detect failures. In 1979, Morris et al. used second harmonic generation in order to supervise the evolution of fatigue cracks in aluminum alloy [22]. Then in 1994, Korotkov et al uses sound modulation excitation by vibration to detect defects in steel [23]; Nagy in 1998 uses nonlinear ultrasonic characterisation to detect fatigue crack in plastics, metals, composites and adhesives [24]. Then in late 2000, Van Den Abeele et al. demonstrated the propagation of harmonics and sidebands as a result of damaged properties in Plexiglass and sandstones [25].

Among the most paramount finding is by Donskoy and Sutin (1999) [26] using the modulation of ultrasound by low frequency vibration to detect defects like cracks, debonding and delamination in steel pipe. Then in the same year, Zheng et al. uses nonlinear acoustic imaging to interpret the degree of material disturbance cause by the asymmetry of lattice structure and disorder in crystals [27].

In general, nonlinear acoustic wave modulation is the interaction between acoustic waves and the low frequency vibration. This has been the parameter practically studied in order to measure the degree of damage in a material. Then in year 2000, Van Den Abeele et al. present a new technique called Nonlinear Elastic Wave Spectroscopy (NEWS) where this technique excite two frequencies at the same time to a specimen in order to detect damage [28]. The detection is based on the inspection on the harmonics and sidebands of the frequencies excites on the specimen [28]. Advancement of technologies enable the used of low-profile piezoceramic actuator and lead zirconate titanate (PZT) transducer to introduce synchronously low-frequencies excitation and high-frequencies ultrasonic waves accordingly to the test specimen [17, 29]. Degree of sidebands around the high-frequency peak were analysed in order to identify micro crack. Novel nonlinear-modulation method was proposed for crack detection using cross modulation effect generated from a gradually increasing amplitude-modulated firm excitation and a probe signal. The schematic figure is shown as in Figure 2-5 [30].