ANALYSIS OF WAVE AMPLITUDE MODULATION EFFECT FOR VARIABLE CRACK ORIENTATIONS IN VIBRO ACOUSTIC INSPECTION METHOD -SIMULATION APPROACH-

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This thesis is submitted in partial fulfilment of the requirement for the award of a Bachelor Mechanical Engineering (Design & Innovation)

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SUPERVISOR DECLARATION

“ I hereby declare that I have read this thesis 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 (Design & Innovation)”

Signature :..

Supervisor :...

Date :..

DECLARATION

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

Signature : ....

Author : ....

Date : ………………………………..

DEDICATION

I dedicate this report to my loving parents, Mr. Mahmud Bin Abdul Jalil and Madam Noorazizun Binti Abdul Aziz that always support me till my report is done. They also advice and give me strength to finish this report as soon as possible. Thank you very much. I will appreciate it.I also want to thanks to all my lecturer and friends that always support me and show their fully cooperation to finish this report.

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Firstly, I would like to express my deepest thanks to my supervisor, Dr. Ruztamreen Bin Jenal because give me opportunity and chance to complete this report. As my supervisor who had guided a lot of task during this semester session 2012/2013. I also want to thanks the lecturers, technician and staffs of FKM for their cooperation during I complete this project that had given valuable information, suggestions and guidance in the compilation and preparation this project report.

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ABSTRACT

Nonlinear vibro-acoustic is a highly reliable and sensitive method for damage detection. It is a method based on propagation of high frequency acoustic waves in solid structures with low-frequency excitation. The interaction between acoustic waves with material changes will cause wave distortion effects. Nonlinear acoustic modulations are investigated for fatigue crack detection. The focus in this project is used for crack detection in aluminium plate. Finite Element (FE) modelling is used to establish frequencies of modal and ultrasonic excitation. The plate is divided into two types which is uncracked plate and cracked plate. The crack plate will be design at difference orientation between them. The models of plat will be simulating by using Abaqus software to get the natural frequency and mode shape. The node displacement point also will be creating at below and above cracked line. The average of R-value for crack orientations will be shown after running a transfer function by using Matlab software. The relationship between average of R-value and crack orientations will be plotted.

ABSTRAK

Vibro-akustik tak linear adalah satu kaedah yang sangat dipercayai dan peka untuk mengesan kerosakan. Ia adalah satu kaedah yang berdasarkan perambatan gelombang akustik frekuensi tinggi dalam struktur pepejal dengan pengujaan frekuensi rendah. Interaksi antara gelombang akustik dengan perubahan bahan akan menyebabkan kesan herotan gelombang. Modulasi akustik tak linear disiasat untuk pengesanan retak. Projek ini fokus kepada kesan retak pada plat aluminium. Permodelan Unsur Terhingga (FE) digunakan untuk mewujudkan frekuensi pengujaan bermodal dan ultrasonik. Plat ini dibahagikan kepada dua jenis iaitu plat tidak retak dan plat retak. Plat retak akan dilukis dengan perbezaan orientasi. Model plat akan disimulasi dengan menggunakan perisian Abaqus untuk mendapatkan frekuensi tabii dan bentuk mod. Jarak nod juga akan dihasilkan di bawah dan atas garisan keretakan. Purata nilai R untuk orientasi retak akan ditunjukkan selepas menjalankan fungsi pemindahan dengan menggunakan perisian Matlab. Hubungan antara purata nilai R dan orientasi retak akan diplot.

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I = intensity of oscilation

ω = frequency

r = radius

R = intensity of modulation

H_0 = transfer function for crack plate

H_c = transfer function for uncrack plate

B_0 = min. signal modulation

B_1 = variation"peak-to-peak" modulation

H_{ij}= transfer function for frequency

ω_n = natural frequncy

n = mode

Q_n = damping factor

f = natural frequency

k = stiffness

m = mass

f_u = natural frequency for uncrack plate

f_C = natural frequency for crack plate

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In engineering field, a Structural Health Monitoring (SHM) is a common approach for maintaining a performance, structural and safety. This is applied in various structures such as aircraft, bridge and offshore platforms. An addition, SHM can refer as a process of damage detection and characterization of the damage for further maintenance strategies. There are several of damage detection methods and damage monitoring systems that can measure the damage of structure.

A few of techniques in Non Destructive Testing (NDT) are used to detect cracks in materials and structures. It is consists of eddy current (ECT), acoustic emission, ultrasonic testing (UT), radiography (RT), magnetic particles and visual inspection. However, these techniques are not possible in some situations. It is because a researchers need to access a component under analysis for crack detection. However, this problem can be solved by replace to vibration based inspection (Yang, X.F 2001). This is because a measurement and collection parameters such as natural frequency of vibration is easy to develop. This method also does not require a smooth surface compared to other methods. Vibration based inspection also can be used to detect cracks in a long distance. In addition, vibration based inspection also cheap and fast method.

In recent years, the uses of vibration based on inspection are increasingly used by engineers and also mathematicians. There are various models of the crack related with vibration based inspection method. (Rizoz P.F et al. 1997) has developed a cracking model and calculate the mode of vibration based on the size and position. However, some of the researchers use the finite element method (FEM) to detect a crack in a structure. In fact, FEM is the main method can be used in cracking detection (Li B. et al. 2005).

A variety of non-linear phenomenon has been used in non-linear acoustic to detect cracks in metallic structures. This is including the frequency modulation, side bands, resonant shifting and harmonic generation. The physical of the structure does not to analyse although all these effects are early stages of damage detection. However, it was generally agreed that the interaction between high frequency acoustic waves and low frequency mode of excitation is important to detect cracks (Jenal R. 2010).

A simulation study on non-linear acoustic effect for crack detection in plate structure is a method in which the simulation can detect non-linear acoustic effects on the structure. Non-linear acoustics can investigate the damage of small or large damage. Normally, it is very faster to conduct investigations (Zaitsev V. et al. 2000).

For this project, the model analysis that has been used is aluminium plate. From the result, the intensity of R will be analysed to obtain the non-linear acoustic effects at the crack plate. Then, the result of crack plate is compared to uncrack plate.

1.2 PROBLEM STATEMENT

Nonlinear acoustic is an effective method used to detect fatigue crack orientation in solid structures such as fatigue cracks, debonding, corrosion, delamination and others. Nonlinear acoustic effects can be observed and analysed to estimate the presence of crack in structure and the natural frequencies of its structure.

Therefore, natural frequency effecting nonlinear acoustic effects as the presence of crack in structure is investigate in this project.

1.3 OBJECTIVE

The objectives of this project are:

1. To perform nonlinear vibro-acoustic simulation to analyse fatigue crack orientation in aluminum plate.

2. To determine the relation between crack orientation with R value.

1.4 SCOPE OF WORK

Scopes of work for this project are:

1. Simulate a modal analysis for crack and uncrack plate with various crack orientation by using Finite Element (FE) Modelling.
    a) Simulate a modal analysis by using Abaqus software.
    b) Create a modal plate for uncrack and crack plate.

c) Set up the characteristics of the modal plate that has use which is consists of density, young modulus and poisson's ratio.
d) Use the mesh size to 4 m.
e) Create a modal for crack plate which is various in orientations. The orientation is set up to 0º, 22.5°, 45º, 67.5° and 90º.
f) Extract 1700 natural frequencies and mode shapes.

2. Analyse transfer function for the simulated mode shape of the aluminum plate.
   a) Find the transfer function value to calculate the R value.
   b) Find the relationship between natural frequency and analysis result.

3. Determine the wave modulation index (R value) by using analysis results.
   a) Extract the nodal displacement in transfer function. The distance of the nodal point is 30 mm at below and above crack line.
   b) Determine the coordinate of the nodal displacement and calculate it by using transfer function.

4. Determine the relation between crack orientations with the R value.
   a) Analyse the relationship between average R values with crack orientation.
   b) Analyse the natural frequency for crack orientation.

1.5 SUMMARY

As summary of the report, the project conducted by using Finite Element (FE) analysis to create and analysis a model plate. The transfer function value is determined to calculate the R value.

Chapter 2 is explaining the scientific research that has been done during the study. It is consists of information through reference resources such as journals, theses, and so on. Most of the information that present in chapter 2 is the nonlinear acoustics, crack detection method, modelling or finite element modelling and the topics that have relevance to the study.

Chapter 3 is explaining a modal analysis of the aluminum plate. The modal analysis by FE method use an Abaqus software package to extract the natural frequencies and mode shape for the uncrack and crack plate In addition, this chapter also describes the method or step to create a modal analysis.

The results for modal analysis are described in chapter 4. It is about the percentage of frequency shifting against crack orientation and also average of R value against crack orientation. The results are shown by the graph.

Chapter 4 also describes the discussion from the result. In addition, the relationship between the R value and crack orientation are also defined in this chapter. After that, the overall conclusion of the report will be described in chapter 5. In which the conclusion is based on the objectives of the study.

CHAPTER 2

NON-LINEAR ACOUSTIC

2.1 INTRODUCTION OF NON-LINEAR ACOUSTIC

In recent years, the application of non-linear methods to investigate structural damage based on acoustic wave has started receiving attention from many researchers. This is due to its ability to detect small damage. In addition, it may detect cracks in a structure more easily compared to linear measurements. Non-linear acoustic is a technique to investigate unrelated wave signal with the input signal (Jenal R. 2010). Below are the main effects based on non-linear acoustics:

I. Resonant Shifting
II. Wave motion: Side Bands Generation
III. Amplitude Modulation
IV. The Principle of Harmonic Motion

In addition, this method can be able to investigate the different types of materials as well as various types of damage. Other than that, it also can be used to investigate various types of materials and component of design. For both applications, the technique is found to be able to conduct investigates more quickly. This is proven by Johnson, in "Los Alamos Seismic Research Laboratory" and he said in his report about the technique or method of investigation using non-linear acoustics, according to his research this is a fast technique to evaluate qualitatively about whether a component in good condition or not (Johnson, P.A. 1999).

However, since year 1970, there are so many researches that have carried out on the non-linear acoustic effects. They are consists of Rudenko, Sutin and Zaitsev. In addition, the (Morris et al. 1979) has been using second harmonic generation for monitoring fatigue crack growth in aluminium alloy and then followed by (Shkolnik, I. 1993), and he has been using a non-linear ultrasonic parameter to study the characteristics of the concrete material . After that, the research is followed by Korotkov, and he was using the modulation sound through vibration to detect the damage of steel and Sutin and Nazarov have been together using non-linear acoustics to detect the cracks in the metal (Korotkov et al. 1994). (Zaitsev et al. 2000) have demonstrated the basic principles of non-linear acoustics in solid materials using the interaction between high frequency and strong pump wave. Nagy was exploited the features of non-linear ultrasonic to detect fatigue cracking in plastics, metals, composites and adhesives (Nagy P.B 1998). Then, followed by (Van Den Abeele et al. 2000) and he shows a harmonic generation and the side bands based on the characteristics of damage of sandstone and plexiglass.

Generation of non-linear acoustic waves are caused by the interaction between acoustic waves and low frequency vibration. This has been proven through researches that have been conducted to detect the damage in a material. As evidence, Xiao and Nagy have used echo graph ultrasonic techniques to detect the very small cracks. This technique use a thermo-optical modulation through out of infrared rays to produce heat stress on the specimen surface and use high frequency ultrasonic waves to detect very small damage. In addition, (Van Den Abeele et al. 2000) have introduced the "Non-linear Elastic Wave Spectroscopy (NEWS) technique" which this technique applying two frequency bands on the specimen and detecting the damage based on the harmonic and side band. Zaitsev et al, 2006 also introduced a non-linear method for detecting cracks. Apart from these results, there are many non-linear applications in the research.

2.1.1 Resonant Shifting

Resonant shifting is the ability of a system to oscillate in higher amplitude compared to other frequencies. It also called resonating frequency. All this frequency does not matter even it is small, but it has the ability to oscillate in higher amplitude. This is because the system has a vibration.

Resonating system will occur when a system is able to store and transfer energy between two different storage modes, such as kinetic energy and potential energy in a pendulum. However, there is a loss from one cycle to another cycle, which is also known as immersion. When there is a small immersion, the frequency will resonate with the natural frequency, which is the frequency of forced vibration.

The system will resonate frequency phenomenon occurs in all types of frequency or wavelength, where is consists of the mechanical vibrations resonate, acoustic resonant, electromagnetic resonant, resonating nuclear magnetic (NMR), electron spin resonates (ESR) and functions of the quantum resonate. Resonating system can be used to create vibrations at certain frequencies or remove certain frequencies from a more frequency of complex vibration. Resonating system is a system that has been introduced by Galileo Galilei when he conducted an investigation of the pendulum and the musical ropes early in 1604 (Jenal R. 2010).

The response of resonate especially at higher frequencies from the resonating frequency is dependent on the state of the system and it is usually not symmetric at resonating frequency. This is can be seen in Figure 2.1 for ordinary harmonic oscillator. For oscillator with a linear immersion of resonating frequency, Ω, the intensity of oscillations, I when the system is driven by a frequency, ω can be shown on the resonating frequency equation as equation (2.1):

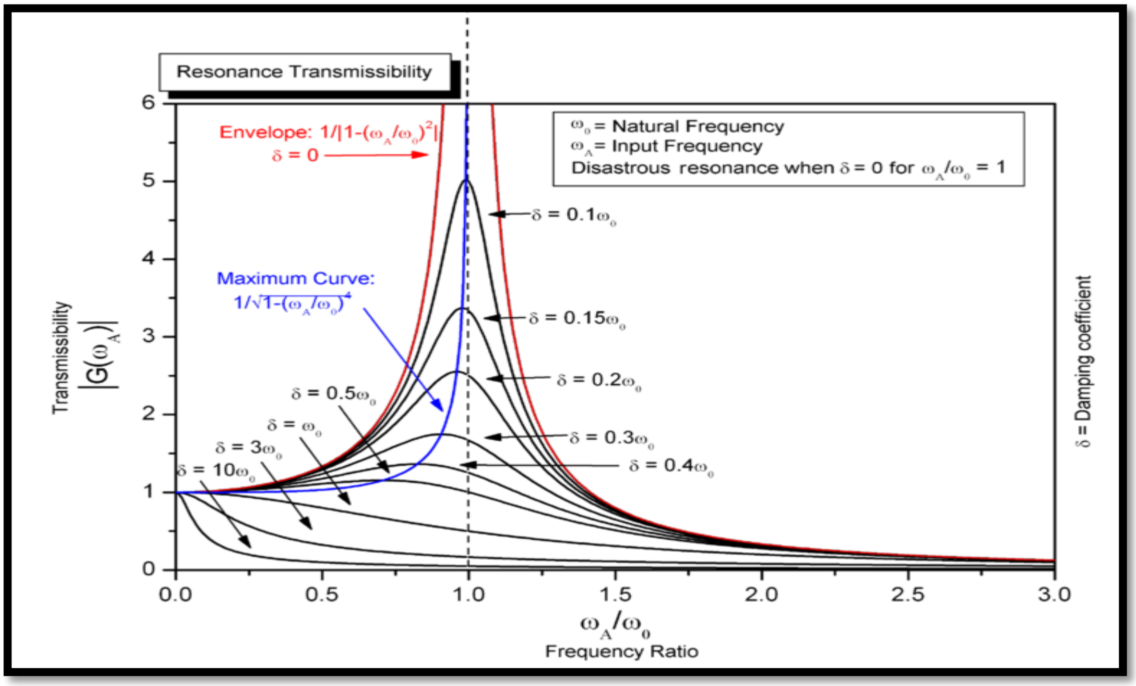

Figure 2.1: Harmonic oscillator, (source from
http://en.wikipedia.org/wiki/File:Resonance.PNG)

$$I\ (\omega) \propto \frac{\frac{r}{2}}{(\omega-\Omega)^2+\left(\frac{r}{2}\right)^2} \qquad (2.1)$$

The intensity is the squared amplitude of the oscillations. This is a Lorentzian function and the response is found in many physical conditions involving resonates system. r is a parameter that depends on the immersion oscillator. The length of pendulum is inversely proportional to the *Q* factor which is used to get an echo. In electrical engineering, the response is known as the universal curve. It was introduced by Frederick E. Terman in 1932 to show the analysis of the radio circuit in the middle frequency range and *Q* factor.