THE EFFECT OF TEMPERATURE AGAINST NONLINEAR EFFECT IN VIBRO-ACOUSTIC METHOD ON SOLID STRUCTURE

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KESAN SUHU TERHADAP KESAN NONLINEAR DALAM KAEDAH VIBRO-ACOUSTIC PADA STRUKTUR SOLID

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Laporan ini dikemukakan sebagai memenuhi sebahagian daripada syarat penganugerahan Ijazah Sarjana Muda Kejuruteraan Mekanikal

Fakulti Kejuruteraan Mekanikal

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this project report entitled "The Effect Of Temperature Against Nonlinear Effect In Vibro-Acoustic Method On Solid Structure." is the result of my own research except as cited in references.

Signature : ………………………………

Name : Muhammad Hafidzal Bin Mohd Shahrin

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PENGAKUAN

Saya akui laporan ini yang bertajuk "Kesan Suhu Terhadap Kesan Nonlinear Dalam Kaedah Vibro-Acoustic Pada Struktur Solid" adalah hasil kerja saya sendiri kecuali yang dipetik daripada sumber rujukan.

Tandatangan : ....

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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

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PENGESAHAN PENYELIA

Saya akui bahawa telah membaca laporan ini dan pada pandangan saya laporan ini adalah memadai dari segi skop dan kualiti untuk tujuan penganugerahan Ijazah Sarjana Muda Kejuruteraan Mekanikal

Tandatangan :..

Nama Penyelia : Dr. Ruztamreen Bin Jenal

Tarikh :...

DEDICATION

Special Dedication to my family members,

my friends, my fellow colleague and

all faculty members

For all your care, support and believe in me.

DEDIKASI

Dedikasi Khas kepada ahli keluarga saya,

kawan saya, rakan sekerja saya dan

semua ahli fakulti

Untuk semua penjagaan anda, sokongan dan percayalah kepada saya.

ABSTRACT

The purpose of this research is to define the relationship of effect of temperature against nonlinear affect in Vibro-acoustic method on solid structure. Every structure on the machine that was running will be crack because of vibration. How the size of crack we don't know and it is not easy to find it plus with the certain type of temperature. Therefore, nonlinear vibro-acoustic technique will be used to find or analyse the crack detection. This method is convenient and effective non-destructive detecting approach. It can be applied to various types of materials and can even be used to detect various types of defects. Mostly the researcher used this method to detect the crack. The method considered in this study is based on a combined vibro-acoustic modulation of an intensive low-frequency (modal) vibration (Low frequency) and a weaker high-frequency ultrasonic wave (High frequency). Non-linear acoustic modulation is caused by the crack opening or closing. But it also may be possible that a cracking occurs by heat dissipation that may affect a material structure. So that, an experiment will be setup to analyse and identify the relation of the heat dissipation on solid structure with the intensity of the non-linear acoustic modulation. Modal test and vibro-acoustic test was performed on the aluminium plate to find the frequency and intensity. Finally, the contribution of the heat dissipation against the non-linear acoustic effect for crack detection will be explain and show the result of the research. The result from the experiment show that the heat dissipation does not affect to the

intensity of the experiment. There is no distortion of the wave when propagate through the aluminium plate.

ABSTRAK

Tujuan kajian ini adalah untuk menentukan hubungan kesan suhu terhadap kesan tak linear dalam kaedah Vibro-akustik pada struktur pepejal. Setiap struktur pada mesin yang sedang bergerak akan menjadi retak kerana getaran. Bagaimana saiz keretakan kita tidak tahu dan tidak mudah untuk mencarinya ditambah dengan jenis suhu tertentu. Oleh itu, teknik vibro-akustik bukan linear akan digunakan untuk mencari atau menganalisis pengesanan keretakan. Kaedah ini mudah dan pendekatan berkesan yang tidak merosakkan. Ia boleh digunakan untuk pelbagai jenis bahan dan boleh digunakan untuk mengesan pelbagai jenis kecacatan. Kebanyakan penyelidik menggunakan kaedah ini untuk mengesan keretakan. Kaedah ini dipertimbangkan dalam kajian ini berdasarkan modulasi vibro-akustik gabungan getaran frekuensi rendah (modal) intensif (frekuensi rendah) dan gelombang ultrasonik frekuensi tinggi yang lebih lemah (frekuensi tinggi). Modulasi akustik bukan linear disebabkan oleh pembukaan atau penutupan retak. Tetapi juga mungkin keretakan berlaku oleh pelesapan haba yang boleh menjejaskan struktur material. Jadi, eksperimen akan menjadi persediaan untuk menganalisis dan mengenal pasti hubungan pelesapan haba pada struktur pepejal dengan intensiti modulasi akustik bukan linear. Ujian modal dan ujian vibro-akustik dilakukan pada plat aluminium untuk mencari kekerapan dan keamatan. Akhir sekali, sumbangan pelesapan haba terhadap kesan akustik bukan linear untuk pengesanan retak akan dijelaskan dan menunjukkan hasil penyelidikan. Hasil

daripada eksperimen menunjukkan bahawa pelesapan haba tidak mempengaruhi keamatan eksperimen. Tidak ada penyelewengan gelombang apabila disebarkan melalui plat aluminium.

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TABLE OF CONTENTS

ABREVIATION

HF	High-frequency
LF	Low-frequency
USB	Upper Side Band
LSB	Lower Side Band
IM	Impact-Modulation
NEWS	Nonlinear Elastic Wave Spectroscopy
NRUS	Nonlinear Resonant Ultrasound Spectroscopy
NWMS	Nonlinear Wave Modulation Spectroscopy
VAM	Vibro-Acoustic Method

NOMENCLATURE

A_0	Fundamental frequency amplitude
A_1	First sideband amplitude
A_2	Second sideband amplitude
R value	Ratio of first sidebands amplitude over fundamental frequency amplitude

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CHAPTER 1

INTRODUCTION

1.0 Introduction

The first part of this chapter consists of the project background, and the reasons why it was carried out. The next part focuses on the detailed problem statement that leads to the designation of the project. The objectives and scope of the project wad stated in the next part of the chapter that helped the researcher to finish this project. The last part of this chapter is the advantage of the project which to know what did we get from this research.

1.1 Backgrounds of study

Structural damage caused by a particular item may increase the cost of maintenance in which to ensure the production process can run smoothly. How many methods have been used to ensure that maintenance work can be done without a high cost in the event of damage to a structure? Nowadays, the application of vibro-acoustic methods for damage detection has been investigated for many years. The method uses the measurement of weak high-frequency wave modulation responses against the perturbation of stronger low-frequency vibration. The use of this method is due to its advantages in detecting micro defects and detecting signs of damage earlier than traditional linear use. In comparison to linear analysis, nonlinear analysis is a method of analyzing wave signal outputs which are unrelated to the signal inputs (i.e. wave amplitude and speed, scattering coefficient) [1]. The most common nonlinear effects which are highly depending on the wave propagating medium are the generation of frequency modulation, side bands, changes in resonance frequencies, and generation of greater harmonics. Although some of these effects are important for incipient damage detection, their physical clarification remains not well understood. Nonlinear effects such as amplitude modulation are better referred to as interaction of the wave with a micro-inhomogeneous medium [1, 3]. It is a common found by most research that nonlinear effects are highly correlated with defects like discontinuities present within the medium. This method can be applied to various kinds of materials and may even be used to detect various types of defects. For example, detect defects like cracks, de-bonding and delamination in the metallic pipe. The nonlinear effect also can use nonlinear acoustic imaging to evaluate levels of material disruption because of the asymmetry of a lattice structure and dislocation in crystals.

1.2 Problem Statement

This research will analyze the relationship between the temperatures with the nonlinear vibro-acoustic method. We need to investigate either it will affect the propagation of the sound or not. The type of wave distortion, wave delay and amplitude dissipation will be observed in this project. This study will be focused on the mechanism due to the behaviour fatigue crack surface interaction that caused the nonlinear acoustic effect. There are few of mechanisms involved in the phenomena such as heat dissipation from the crack surface due to the friction and heat dissipation from the elasto-plasticity action at crack tips based on research studied by R B Jenal [1].

Different amounts of thermal gradient cause different parts of an object to expand. This differential extension could a chance to be comprehended as far as stress or of strain, equivalently which is called thermal expansion. At certain a point, the stress will exceed the strength of the material, causing a crack form on the structure. In this case, the workers don't know when the structure will start brakes after the temperature on the structure is increased. The duration of the structure of a damaged structure cannot be determined by sight or hearing. Each structure has its own unique properties where the life span of the structure cannot be determined precisely. In this study, it becomes a problem when the temperature is applied to the crack area. The warmer the crack area, making it worse to cause damage if it continues to use it. The object's structure will fail if nothing stops this crack from propagating through the material. To ensure that there are no failures to the structure, that conditions must be regularly monitored.

1.3 Objective

This study is to analyze and investigate the relationship between heat dissipation from a small area at small heat capacity in a rectangular aluminium plate with the nonlinear vibro-acoustic effect such as the amplitude of modulation effect. From the relationship, the minimum value of heat capacity that produces a significant nonlinear acoustic effect will be determined. Finally, the contribution of the heat dissipation against the nonlinear acoustic effect for crack detection will become more explainable.

1.4 Scope of Project

There are three scopes for this project. The primary scope is to study about the impact of temperature due to the nonlinear wave. During this scope, the experiment evidence showing the distortion of an elastic wave with the variation of thermal condition are investigated. The information about the minimum of heat changes that may distort the wave propagation are often gained. The second scope is to design an experimental approach, parameter an instrumentation and to analyze the frequency of the mode and crack on the aluminium plate.

During this experiment, the low frequency, high frequency, and also the output is going to be studied. Besides, low frequency, high frequency and heat capability from the heat sources additionally are studied. The last scope is to analyze the wave propagation through the heated structure. From the result, the sort of wave distortion such as amplitude dissipation and wave delay caused by the heat change can be determined. Besides, the modulation intensity of the structure is going to be calculated and compare.

1.5 Advantages of Project

There are several advantages of this project that would affect the implementation of this project. For the first advantage is the technicians know when the structure will be damaged. From this project, we can estimate the lifespan of the structure by doing the analysis. Besides, this project also can ensure that the maintenance cost is lower due to the crack on the structure. It is because the technician will be fix the broken part before it becomes more broken and affects the others part. Lastly is this project makes the machines operate longer due to lack of damage to the structure. The process of producing the product will not be disturbed due to damage to the machine as the schedule for machine maintenance has been set earlier.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

In this chapter, we will discuss the nonlinear vibro-acoustic and its application, the effect of the nonlinear vibro-acoustic and its mechanism. Many researchers have performed to ensure there is no failure to the structure caused by the cracks to develop the structural integrity monitoring techniques.

2.1 Modal Analysis

The modal analysis could be a methodology of analyzing the dynamic response of the structure once excited by a cyclic force. It's a technique for extracting the resonant frequencies of the structure. by experimentation, modal analysis is completed by impact hammer modal testing, modal shaker testing, etc. usually the experiment is applied by giving an excitation input among a frequency range on a point of the structure and responses of the structure are measured from one or multiple output points. The measured data are analyzed by plotting in the frequency domain in order to identify the peak response of the structure's resonant frequency. The measured data from multiple points will be plotted against the surface coordinates to get the structure's mode form.

It is essential to investigate the modal parameters of a cracked plate in order to know the behaviour of movement of crack edges in an exceedingly plate and plate surface responses to the low-frequency excitation in vibro-acoustic testing. These results then are valid with an experimental modal test.

It is well-known that every solid body or structure has unique natural resonant frequencies. The structure will respond extensively to an external cyclic force excited at one in each of its resonant frequencies. The resonant frequency is a dynamic property for the structure that is incredibly helpful in engineering fields. It's an essential element within the design field and is widely used for investigating the behaviour of a material. As an example, Nonlinear Resonance Ultrasound Spectroscopy (NRUS) [16] is a technique of using shifting of the resonant frequency to identify the nonlinear elastic property of a material.

2.2 Nonlinear vibro-acoustic wave modulation

New frequency harmonics and frequency/phase modulations can also appear in sound characteristics. These additional nonlinear effects are often used for fatigue crack detection. Vibro-acoustic method or technique is advances and reliable for detecting incipient damage like fatigue crack [24]. This method is based on the propagation of high-frequency acoustic waves in solid structures with low-frequency excitation. The wave distortion effects occur when an interaction of the acoustic wave with changes in material or geometric properties. The causes, called nonlinear acoustic effect, are amplified with low-frequency excitation [1]. The detection of micro-cracks is very important in aircraft parts, refinery plants, or nuclear power plants which will detect the crack at the early stage in order to ensure their structural safety. Ultrasound has been widely utilized in the field of non-destructive testing of materials, however, most of these conventional methods using ultrasonic characteristics in the nonlinear elastic region are mostly sensitive to gross defects and opened cracks but for the sensitivity, it is much less to such micro-cracks [23]. Comparing with linear analysis, nonlinear analysis is a technique for analyzing the output of the wave signal that is unrelated to the signal inputs [1]. The most common nonlinear effects that highly depend on the wave propagating medium are the generation of harmonic, amplitude dissipation, sidebands, and resonant wave shifting.

From the 1990s, the application of the methods has been investigated by the researcher. Many researchers have started to study nonlinear acoustic effects for damage detection. It is remarkably the most effective way of detecting the presence of micro or incipient cracks. A simple striking bell example can be used to explain the approach. When a bell is struck, it produces a sound that has contains several acoustic harmonics. The frequency of these harmonics is a unique characteristic of the bell. It is independent on the striking force as long as no changes of the bell geometry and material properties occur. These additional nonlinear effects are often used for fatigue crack detection, as illustrated in Figure 2.1.

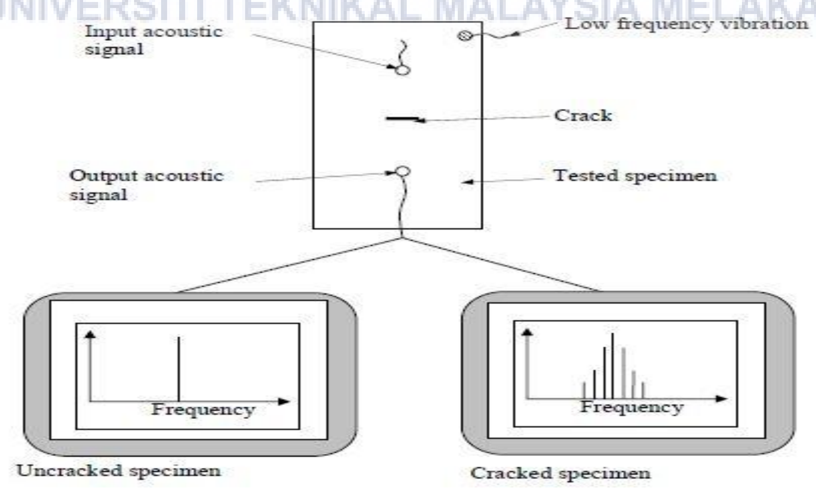

Figure 2.1: Schematic layout demonstrating the principle of nonlinear acoustic used for damage detection [1].

2.3 Nonlinear Vibro-acoustic effect

Effect of the nonlinear acoustic has been studied by many of the researchers. The effect can be analyzing and observing by the present of the broken part on the structure. This effect can be analysed on the resonant frequency shifting, harmonic generation, and sideband generation and amplitude modulation.

2.3.1 Resonant frequency shifting

The resonant frequency is a natural frequency generated by using sound transmitting devices which are used for seismic research. Every structure has a unique natural resonant frequency. It will occur when the external force is applied in a structure which produced the greater amplitude at some of the frequency. The sound receiving device was used to transmit the sound into the ground and natural frequency.

There are many reports that were a response the detection of structural damage regarding to the application of amplitude-dependent frequency, named as Nonlinear Elastic Wave Spectroscopy (NEWS) technique. There are two types of NEWS technique approaches to damage detection structures by the nonlinear wave. One of the methods is Nonlinear Resonant Ultrasound Spectroscopy (NRUS), which it is dependent on the study about the nonlinear response of a single, or a group of, resonant modes within the type of material. The method is extremely useful for basic research and specific applications that do not have strict time requirements in terms of speed of application [15].

The second method is Nonlinear Wave Modulation Spectroscopy (NWMS). This method is based on monitoring nonlinear wave mixing in the material. Wave distortion and accompanying wave harmonics, and in sum and difference frequency generation (sidebands) have appeared from the manifestations of the nonlinear response

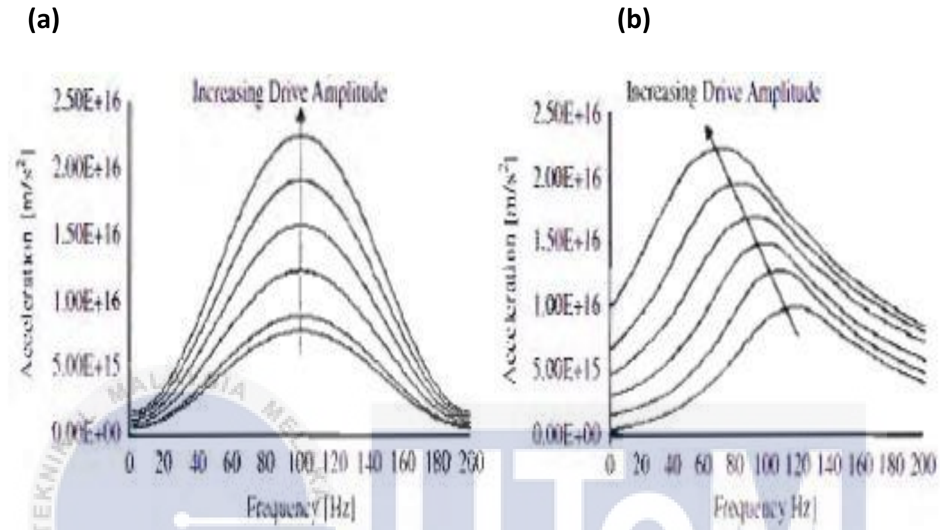

Figure 2.2: Resonant frequency versus drive amplitude. (a) Undamaged sample

(b) Damaged sample. [15]

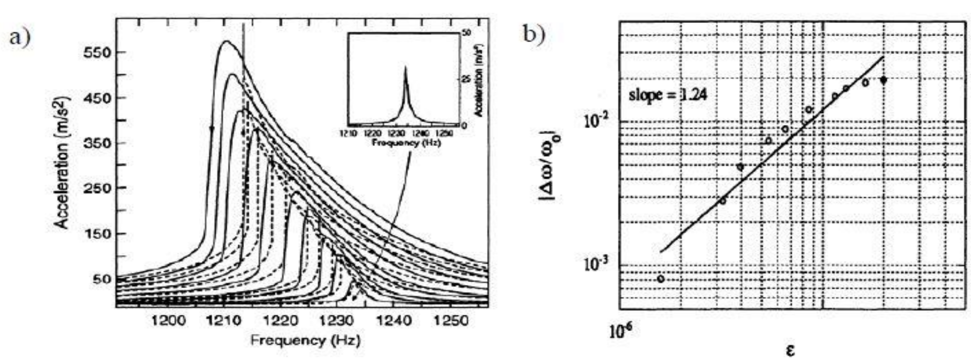

Figure 2.3: An example of (a) resonance peaks shifting and (b) ratio of the resonance shifting against strain level for sandstone material. [19]

Figure 2.3 shows an example of the resonance peaks shifting and the ratio of the resonance shifting against strain level for sandstone material [19]. The figure shows clearly about the shifting of the resonant frequency which is highly proportional to the strain level.

2.3.2 Harmonic generation

NEWS techniques have been used to observe the harmonic generation effect. Neither NWMS method nor NRUS method can be observed into the inhomogeneous material structure or material that contain voids or/and micro-cracks [15, 16]. Base on the material's nonlinearity, the propagating waves can be distorted. The wave will be produce accompanying harmonic (Multiplication of the fundamental wave frequency).

Cause of wave distortion is related to the mechanism of crack opening and closing (Kawashima et al, 2002) [18]. They predicted that when the crack is in a closed condition, the waves are partially transmitted through the crack, while there is no transmission through the crack when in open condition. Then, another researcher describes that the harmonics are caused by the longitudinal wave travelling across crack interfaces where amplitude depends on the pressure applied normally to the crack interfaces (Buck and Morris, 1978)[20]. The effect of the harmonic generation is due to nonlinear interaction between the propagating acoustic waves with crack defects in a material (Solodov et al, 2001) [7]. The others report also said that they consider the defect of the crack is a nonlinear oscillator with the characteristic of an asymmetrical stiffness due to the non-bonded contact to the interface of the crack structure [6]. That is mean the crack characteristic can create and diversity of nonlinear wave effects through the crack on the structure.

2.3.3 Sideband generation and amplitude modulation

A side band is a band of frequencies higher than or lower than the carrier frequency, containing power as a result of the modulation process. The sidebands consist of all of the Fourier components of the modulated signal except the carrier. All types of modulation produce sidebands. Amplitude modulation is an effect of low frequency signal against amplitude variation of the high carrier frequency sign. Amplitude modulation of a carrier sign commonly consequences in reflect of the sidebands image. The signal components above the carrier frequency represent the Upper Side Band (USB), and those below the carrier frequency represent the Lower Side Band (LSB). (Wikipedia, 2018).

There are many of researcher have been used this effect to detect the crack or damage in structural materials or type of components. It is capable to detect various type of damage including fatigue crack, debonding or delamination, and material corrosion. The shape of sidebands from nonlinear acoustic strategy for damage location in NDE has been broadly considered by numerous analysts such as Van Cave Abeele, Cawley, Zaitsev, Sutin, Staszewski and others. A include of the sideband is that it is profoundly touchy to the conduct of wave proliferation section. Subsequently the impact is competent of recognizing micro-cracks and is exceptionally valuable in recognizing beginning breaks which it isn't conceivable to identify by utilizing straight strategies (i.e. wave speed, wave dissemination).

2.4 Crack detection method

Generally, there are some methods of the amplitude modulation of high frequency ultrasound by low-frequency vibration excitation for damage detection. These methods are Vibro-Acoustic Modulation (VAM) method [17, 24, 25], Impact-Modulation (IM) method [26, 27] and Nonlinear Wave Modulation Spectroscopy (NWMS) [5, 11, 13]. Every method is similar for nonlinear acoustic effects to diagnose material defects but for experimental setup and introduction of the low-frequency vibration and high-frequency vibration is different totally. In this study was focus on Vibro-Acoustic Modulation (VAM) method to find the frequency.

The vibration-acoustic modulation technique involves monitoring the amplitude modulation of an ultrasonic vibration field transmitted through a cracked specimen undergoing an additional low-frequency structural vibration excited by impacts. The experimental setup in figure 2.4 was used by Duffour et al. [10]. The test aims to measure the level of sidebands obtained for various ultrasonic frequencies and low-frequency strain levels. This method is quiet similar to the impact-modulation method. Only the location of the signal receiving transducer is different between both of the methods.

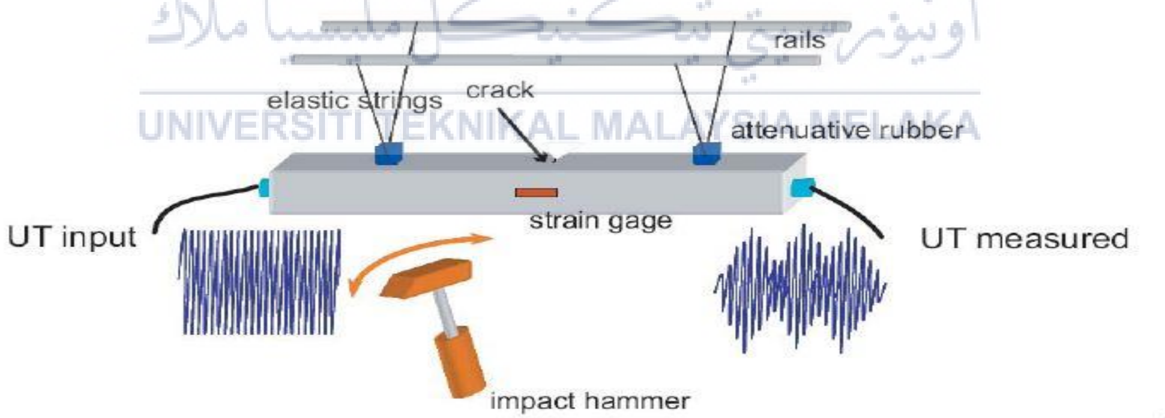

Figure 2.4: Setup of the Vibro Acoustic Method (VAM) testing using impact hammer [25].

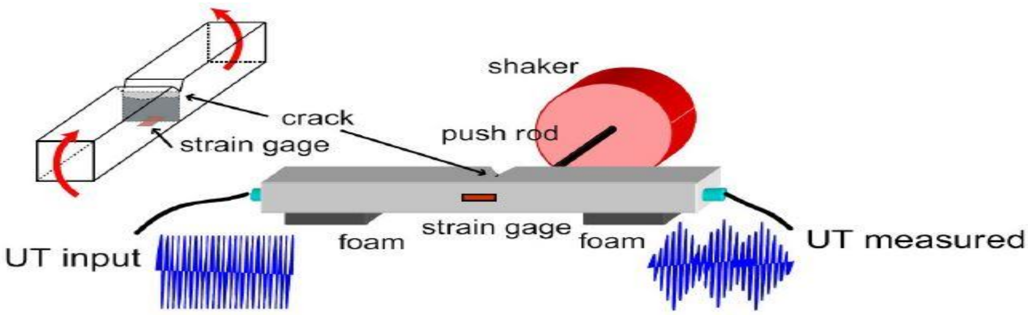

Figure 2.5: Setup of vibro-acoustic method (VAM) by using a shaker [25].

A control shaker is used to replacing the impact hammer to vibrate the specimen as shown in Figure 2.5. This method is more stable to introduce low-frequency vibration than the previous method. However, the interaction between the shaker attachments and the specimen may generate additional nonlinear acoustic effect and increase the noise level in the frequency spectrum. Subsequently, it may hide the sideband effect generates from the specimen defects [25].

2.5 Nonlinear acoustic mechanism

Nonlinear acoustic effects have affected the physical mechanism of the structure. There have much evidence that shows the damaged materials are highly compliant to nonlinear effects while undamaged materials show relatively small nonlinear effects [2, 12, 14]. This part has been explained about what are relate nonlinear effects to material mechanics properties

2.5.1 Open-close of crack faces

Some of the researchers have been explained the interaction between nonlinear crack and wave propagation behaviours. When the interface has tensile stress and compressive stress respectively, the crack will be happening in open-close of crack faces condition. This is based on the result of analytical for the nonlinear dynamic analysis of an unbounded planar interface between two elastic mediums. The onlinear effect is due to the opening and closing phenomenon of crack interfacing (Richardason, 1979) [10]. This conclusion was made based on analytical results of nonlinear dynamic analysis of an unbounded planar interface separating two elastic medium.

Opening and closing behaviour of the crack changes the crack's cross-section and subsequently changes the amplitude of the ultrasonic wave (Duffour et al. ,2005) [4, 17]. They expected that the crack closed condition would transmit the ultrasonic wave the same way as no crack within the transmission way, while, in an open condition, they expected that it would decrease the ultrasonic wave amplitude. From these presumptions, the crack opening-closing cyclic is affecting the ultrasonic wave within the form of a pure sinusoidal wave increased in time-space by a square signal. In practice, the phenomenon is studied quantitatively is frequency domain, where the amplitude modulation is manifest as sidebands around the main carrier speed at the ultrasound frequency.

The presence of the crack in a beam will introduce local flexibility that affects its dynamic response. A crack does not remain always open when during the vibrations. It will open and close over time depending on the loading conditions and vibration amplitudes [21]. The crack may remain in one condition all time, always open or closed depending on the position of crack if the static deflection due to loading on a cracked beam (e.g., the weight of the body beam) is larger than the vibration amplitude.

The mechanism of crack opening and closing as the cause of wave distortion (Kawashima et al.) [18]. The researcher was predicted a closed condition of the waves are partially transmitted through the crack, whereas in an open condition there is no wave transmission through the crack.

2.5.2 Nonlinear elasticity

There is a relationship between the nonlinear acoustic effect to the nonlinear elasticity and energy dissipation in materials. Effect of the elastic nonlinearity of the material would increase more drastically to the presence of crack or micro-contact. Zaitsev, Gusev, et al. [22] said that the nonlinear elasticity of material may result from a certain mechanism. Some of the method can be used to study about the effect of the nonlinear elasticity. Nonlinear resonant ultrasound spectroscopy (NRUS) [5, 9] and nonlinear wave modulation spectroscopy (NWMS) [1, 11, 13] had proposed by Van Den Abeele to observe the effect of nonlinear elasticity. There are also other methods as described in the previous section which has common observations of the nonlinear effects.

Above are techniques that are caused by nonlinear elasticity:

i. Resonant shifts (NRUS),
ii. Harmonics generation (NWMS),
iii. Side bands generation (NWMS).

These effects have complicated compliance with micro-inhomogeneity or micro-cracks within the material even at the mesoscopic scale. Although the total mechanism of the nonlinear effects isn't well understood, the results are often delineated as classical nonlinear physical property or non-classical nonlinear physical property consisting of physical phenomenon and separate memory.

Classical nonlinear elasticity is that the nonlinear relation of a stress-strain curve because of the non-uniform stiffness of material or heterogeneous material properties like density or the presence of small crack that makes weak molecule bonds or contacts separation. Within the classical theory of nonlinear elasticity and within the absence of defects, these background metrics are given geometric objects with no dynamics, and during this sense, not all fields are on the identical footing. These metrics are "absolute" within the sense of Anderson [1967] and "structural fields" within the sense of Post [1997]. It should even be emphasised that the material and close space manifolds are, in general, genuinely completely different.

2.5.3 Temperature

This study is focused on the effect of the temperature to the fatigue crack surface on the aluminium plate that causes the nonlinear acoustic effect due to the frequency of modes. There are few mechanisms involved in the phenomena such as heat dissipation from the crack surfaces due to surfaces friction and heat dissipation from the elasto-plasticity actions at crack tips (R B Jenal) [1].

Others researcher said that a snap-through phenomenon and frequency shifting due to nonlinear large amplitude vibration were observed when he does the studied about the thermally loaded panels under random excitation. From that study, the result showed that the nickel panels have better performance regarding the random acoustic response when in room temperature. However, it turns to be a matter of compromise between having large thermal post-buckling deflection and hence deterioration in the flight performance or having higher vibration amplitudes which can affect fatigue life performance when at high temperature. (Ibrahim et. Al) [8].

CHAPTER 3

METHODOLOGY

3.0 Introduction

In methodology, it describes the series of stages done to complete the project and acquire the objective. Every stage will be explained in more detail in this chapter. The flow and process can be clearly overviewed by a flow chart where it shows the starting of idea initiation to the end which is the preparation of a technical report on the project. The project begins with information collecting on the concept idea of the project so that the objective can be achieved.

3.1 Methodology Flow Chart

Methodology flow chart discusses the process and method involved in the project. It includes the idea initiation through problem statement and project theme provided by faculty followed the information collecting in the literature review.

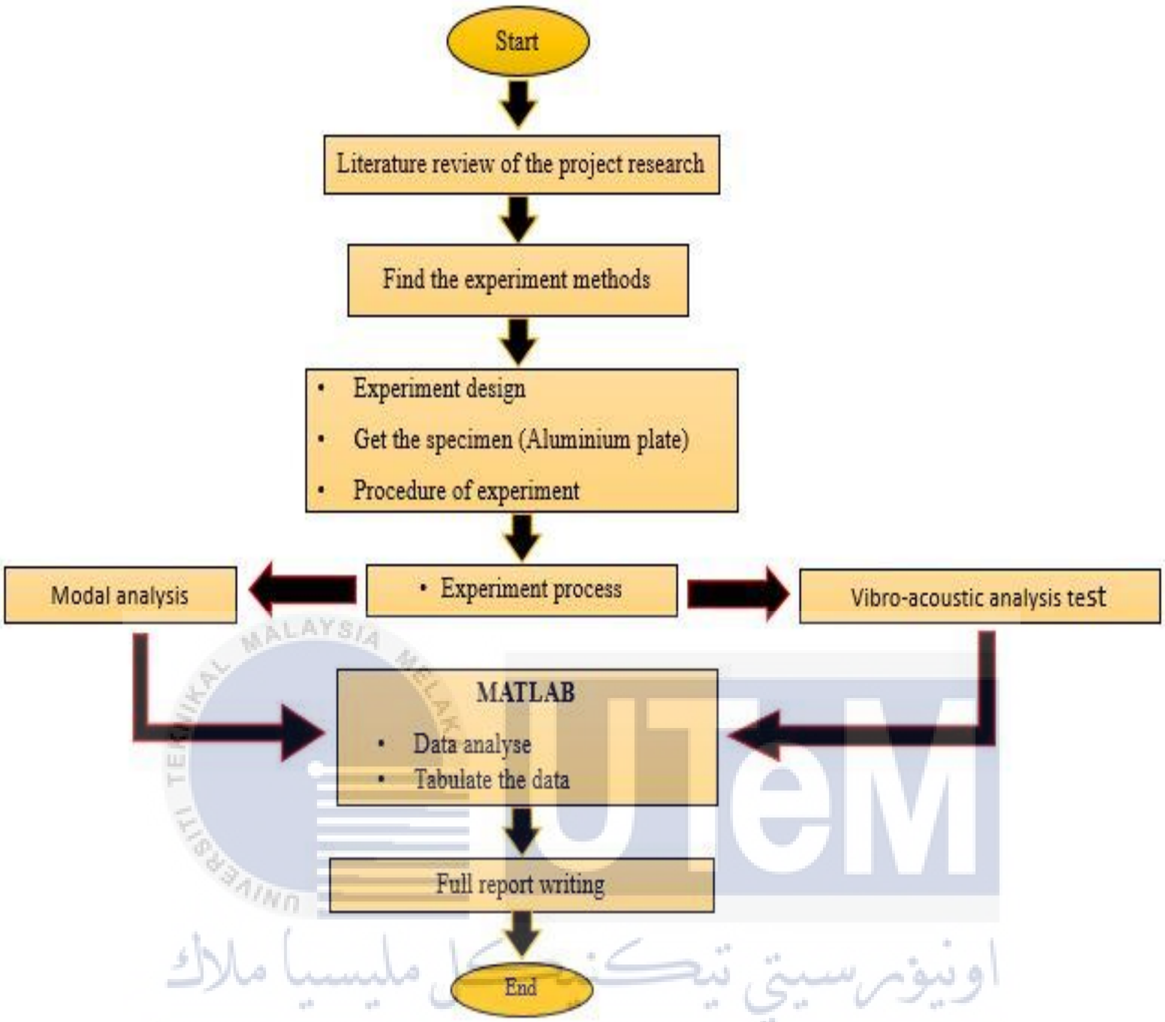

Figure 3.1: Flow chart of the project

Figure 3.1 shows the flow chart of the project. This project begins with a review of the research related to this project and collection of experiment methods. To make these review, there are many of journal, textbook and research papers gathered from the library and internet that have been studied such as nonlinear acoustic method theoretically and experimentally. From this review, the previous experiment method will use as references. After doing the review and collect the experiment method, the new experiment design has been set up. The suitable specimen and equipment have been choosing according to the experimental design. After the specimen and equipment were finished to set up, the process of the experiment is done with the correct procedure. This experiment process includes the modal analysis test and nonlinear vibro-acoustic test. From this experiment, it will generate the data and the result will be saved. Then, the data that have been saved will be used in the MATHLAB. The data is converted to the amplitude-frequency domain. So, the analysis can be made by analysed the frequency components. The data then will be tabulated and show in the frequency graph. Lastly, the final report will be writing and submit.

3.2 Literature Review

Literature review is a process of collecting information related to the project, it usually refers to the study and analysis of previous experiment design. The information is mostly from journal, thesis, patent and others. The literature review will generate an idea based on the requirement of the project theme and finding the current method used. Idea generated can either be an innovation or improvement from previous experiment design.

In this title, the literature review contains the relevance, experiment design, experiment process, experiment method and else. Furthermore, material selection also discussed in this chapter. All the information collected from the references is relevant and it will narrow down the scope of our finding.

3.3 Experimental

3.3.1 Experiment conduct

The structure has various type of amplitude which every of the structure was vibrate with high amplitude of vibration at its resonant frequency. Five to six frequency modes choose from the wave modulation in the frequency time domain. The analysis was performed by experimental works to study about the effect of temperature to the crack due to the properties of the aluminium plate, i.e. length of the crack and mode of the crack, effects to the vibro-acoustic intensity. Three experiments is conducted to do the nonlinear acoustic test on the cracked and un-cracked aluminium plate which is without heater and without crack, with heater and without crack, and with heater and with crack. Study about the analysis is to know the type of physical mechanism in the modulations of the wave in the signal response. The investigated of the analysis is to involve the signal harmonic and modulation sidebands when the temperature is increasing on the aluminium plate.

The method was considered in this study based on the combination between vibro-acoustic modulation of an intensive low-frequency (modal) vibration (LF) and a weaker high-frequency ultrasonic wave (HF). These two excitations are introduced to the structure simultaneously, as illustrated in Figure 3.3.

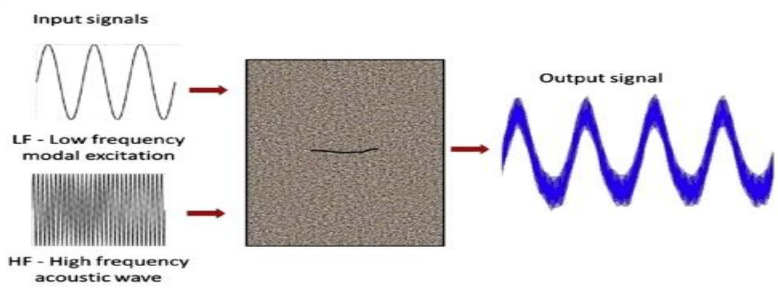

Figure 3.2: The principle of vibro–acoustic modulations.

3.3.2 Equipment and specimen

3.3.3.1 Equipment

1. DPO 4032 Digital Phosphor Oscilloscope

Figure 3.3: Digital Phosphor Oscilloscope

Using parallel processing techniques and a dedicated processor, the DPO uses a separate parallel processor and this enables it to capture and store waveforms despite the fact that the display may be acting much slower. By using the parallel processing the DPO is not limited by the speed of the display, signals could also be captured independently of the activity of the display. These may include spurious pulses, glitches, and transition errors. It also emulates the display attributes of an analog oscilloscope, displaying the signal in three dimensions: time, amplitude and the distribution of amplitude over time, all in real time.

2. Power Amplifier Type BAA 60

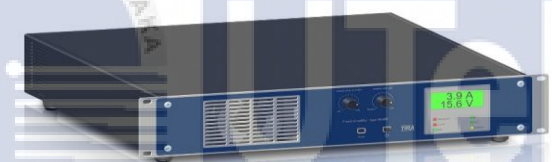

Figure 3.4: Power Amplifire Type BAA 60

The analog power amplifier BAA 60 TIRA has been developed for the vibration test control systems with a maximum of 60 VA. The output of the RMS power has been calculated at a load impedance of 4 Ohm. The frequency of the power amplifier ranges from 40 Hz to 10 kHz at full power or with 5 Hz to 100 kHz with reduced power and minimum harmonic distortion. The device offers extraordinarily stable operation within the desired temperature and voltage range and it is so highly reliable. Its RMS output current limit is variable.

3. Ray-Jr MALL Pyrometer

Figure 3.5: Ray-Jr MALL Pyrometer

The Ray-Jr MALL Pyrometer (Infrared thermometer) is used for measuring the temperature of the object's surface, which is applicable for various hot, hazardous or hard-to-reach objects without contact safely and quickly. The unit consists of Optics, Temperature Sensor Signal amplifier, Processing circuit and, LCD Display. The optics collected the infrared energy emitted by an object and focus onto the sensor. Then the sensor translates the energy into an electrical signal. This signal is going turned out to be digital shown on the LCD once the signal electronic equipment and a processing circuit.

4. AFG3252C Function Generator

Figure 3.6: AFG3252C Function Generator

The function generator is typically a piece of electronic equipment or software system used to generate different kinds of electrical waveforms. A number of the foremost common waveforms created by the function generator are the sine wave, sq. wave, triangular wave and, saw-tooth shapes. These waveforms will be either repetitive or single-shot (which needs an internal or external trigger source). With 12 standard waveforms, arbitrary waveform capability, and signal impairment options, the AFG3252C Series arbitrary / function Generator supports a wide range of application needs with one instrument. Best-in-class performance ensures signals are accurately reproduced. A large show and 25 shortcut keys create the AFG3252C Series arbitrary / function Generator both easy to learn and easy to use.

5. Electromagnetic Shaker

Figure 3.7: Electromagnetic Shaker

Electromagnetic shaker operates on the principle of magnetic. An electric current in a wire will establish a magnetic field. When the wire is wound in a coil the effect of the magnetic field is multiplied because of the multiple winding of the coil. The change of the current flow in the coil will produce a varying magnetic field.

6. XH-W3001 Digital Control Temperature

Figure 3.8: XH-W3001 Digital Control Temperature

Digital control temperature is a controller in a temperature control system will accept a temperature sensor such as a thermocouple or RTD as input and compare the actual temperature to the desired control temperature, or set point. This digital control will provide an output to a control system for the element. Example for this application where the controller takes an input from a temperature sensor and it has an output part that connect to a control element like a heater or fan. The controller is typically only one a part of the temperature system, and also the whole system ought to be analyzed and regarded in choosing the correct controller.

7. Rectangular Alumina metallic ceramic heating element (HTCC)

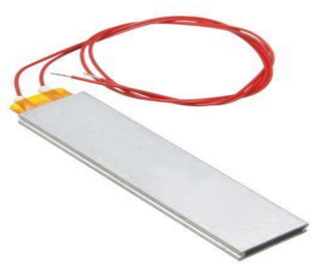

Figure 3.9: Rectangular Alumina metallic ceramic heating element (HTCC)

HTCC is a word form for High-temperature co-fired ceramics; HTCC ceramic heating element is formed from high melting point metal heating material such as tungsten, molybdenum or molybdenum – manganese and 92-96% alumina ceramic substrates. The metal heating resistance slurry is printed onto the tape casting ceramic green body according to the design requirement, several layers of the ceramic green body are then laminated together and are fired at 1500 ~ 1600 °C high temperature, with the aid of 4-8% sintering additive, to create the alumina ceramic heating element. This product can be standing with high temperature, the life cycle is long, features in corrosion-resistant, the surface temperature is uniform, very excellent thermal conductivity and etc.

Figure 3.10: Laser Doppler vibrometer (LDV)

A Laser Doppler vibrometer (LDV) is used to produce non-contact vibration measurements of a surface. It is a scientific instrument that the laser beam from the LDV is directed at the surface of interest, and the vibration amplitude and frequency are extracted from the Doppler shift of the reflected laser beam frequency due to the motion of the surface. The output of an LDV is generally a continuous analog voltage that is directly proportional to the target velocity component along the direction of the laser beam.

3.3.2.2 Specimen

Table 3.1: Material properties of the aluminium plate

Properties Name	Details
Name	Aluminium Al-6061
Density	2700g/m^3
Young's Modulus	68900 MPa
Poisson Ratio	0.33
Dimension	400mm x 150mm x 2mm

The specimen used is a 400 mm x 150 mm x 2 mm aluminium plate. Table 3.1 shows the material properties of the specimen. The material used in this investigation is aluminium AL-6061. It has high strength, good fatigue resistance, and average machinability and is commonly used in aircraft structures such as fuselage structures, wing tension members, shear webs and structural areas. Its density of the material is 2700kg/m3 while Young's Modulus and Poisson Ratio is 68900 MPa and 0.33 respectively.

3.3.3 Experiment design

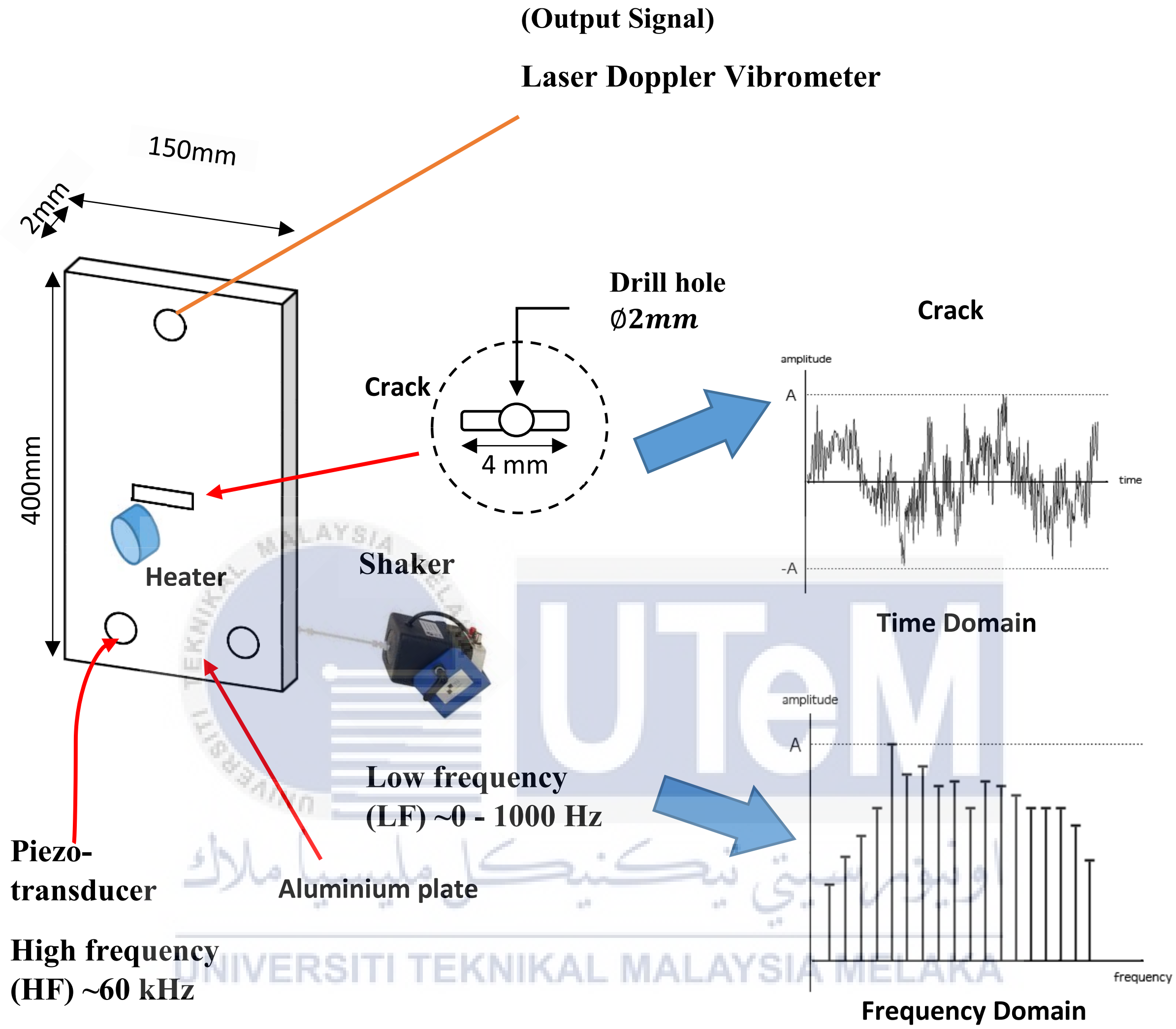

Figure 3.11: Setup of vibro-acoustic method (VAM) by using a shaker as exciter on an aluminium plate.

Nonlinear acoustic tests were performed for both selected natural frequencies of the plate. The Piezo-ceramic transducer for high-frequency excitation was attached to the plate using a two-component epoxy adhesive. An ultrasonic sine wave (HF = 60 kHz) was introduced to the low-profile piezo-ceramic transducer. At the same time, the structure was vibrated using the electrodynamic shaker driven by a sinusoidal excitation (LF = 0-1000 Hz) with the amplitude of 1.000 Vpp. Figure 3.11 illustrates the entire experimental arrangement used for nonlinear acoustics tests.

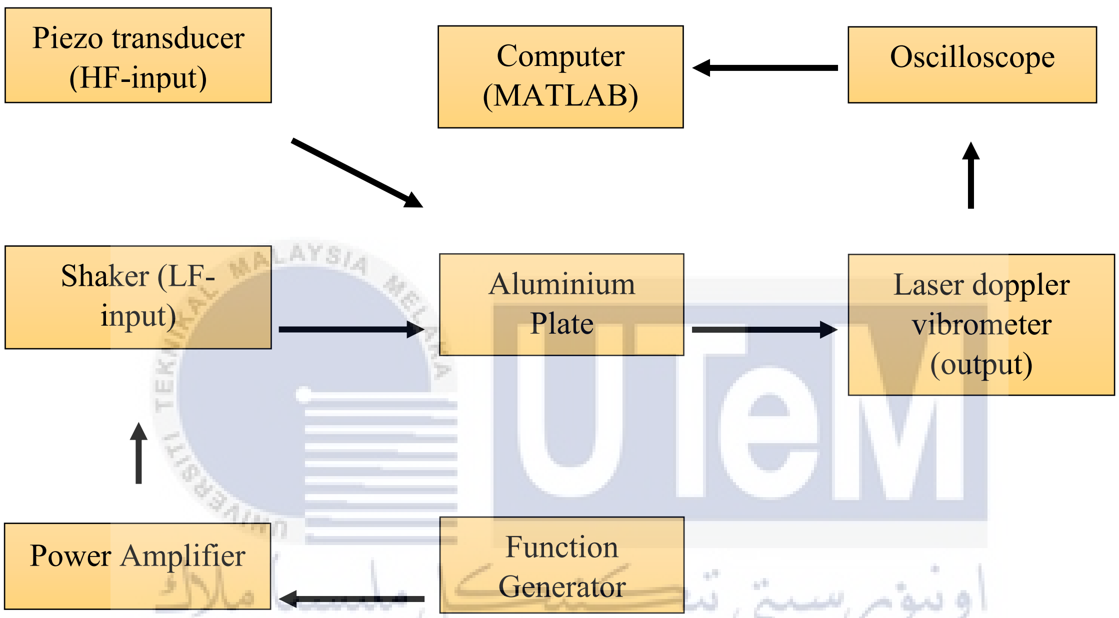

Figure 3.12: Schematic diagram of the experimental setup.

Figure 3.11 and 3.12 showed the setup for this experiment. Firstly, the function generator must be connected with the power amplifier which is used to generate different kinds of electrical waveforms. Then, the power amplifier is connected to the shaker which is to provide drive power for electrodynamic shakers. The function of the shaker is to generate a low-frequency signal to the aluminium plate. To set up the aluminium plate, firstly, the Metal

Ceramic Heater was put on the centre of the aluminium plate. This heater was connected to a digital LED temperature controller thermostat with the probe to control and detect the temperature of the aluminium plate while heating by the heater. Then, the aluminium plate was put on the shaker at the left corner by hanging the aluminium plate by using the straps on the stand provided. The experimental was starts with the modal test which to find the properties of the aluminium plate. The aluminium plate was vibrated using sine sweep vibration mode by electromagnetic shaker from 1 Hz to 1 kHz. Five to six of the vibration mode from the result of the test was selected to use in the vibro-acoustic test. For the first vibration mode, the aluminium plate was harmonically vibrated using "LF exciter" electronic shaker and at the same time, the ultrasonic wave was introduced to the aluminium plate using "HF input" function generator. The heater was used to apply heat on the surface of the aluminium plate. The aluminium plate was heated to 25 ˚C. When the temperature reached 25 ˚C, the temperature control automatic stop the heating. The output signal laser Doppler vibrometer was acquired and show the signal in the digital oscilloscope. The oscilloscope displays the signal in tie domain graph. The data from the graph was recorded. The previous step was repeated with the other different temperature of 27 ˚C, 29 ˚C, 31 ˚C, 33 ˚C, 35 ˚C, 37 ˚C and 39 ˚C. Amplitude-timed graph it was not easy to see the component of the frequency. Therefore, the recorded data was converted by using MATLAB software program. The converted data was used by using the Microsoft Office Excel to create a frequency domain graph. The frequency component can be revealed by using the amplitude-frequency graph (frequency spectrograph).

3.4 Experiment Test

Investigation of the effect of temperature against nonlinear effect in Vibro-acoustic method on a solid structure. In this work, the students are given the plate/s which made of aluminium with dimension 400 mm x 150 mm x 2 mm. To control and conduct the experiments, the students are provided with PZT Transducer, shaker, heater, etc. Experimental modal analyses were performed on the un-cracked and cracked aluminium plate to validate the simulation results.

There are 3 experiment need to conduct on the aluminium plate which;

i. Aluminium plate without crack and, with and without heater.

ii. Aluminium plate without fatigue crack and, with and without heater.

iii. Aluminium plate with fatigue crack and, with and without heater.

Every experiment have 2 type of test which;

i. Modal Test/Modal analysis

ii. Vibro-acoustic Test

Table 3.2: Comparison between modal experiment test and vibro-acoustic experiment test.

Modal Test/Modal Analysis	Vibro-acoustic Test
Without use piezo transducer to get the data.	Use piezo transducer to get the data.
Find properties of the structure as frequency mode in time domain.	Use frequency mode from modal test and set to the shaker to get the frequency domain.
Does not find the intensity of sideband in structure (No sideband)	Find the intensity of sideband in structure (have sideband)

3.4.1 Experimental Modal Analysis

Experimental modal analyses were performed on the uncracked and cracked aluminium plate to validate the simulation results.

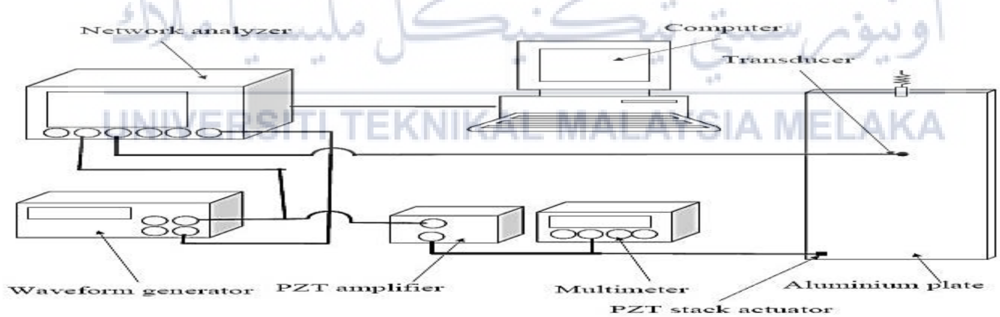

Figure 3.13: Experimental setup and arrangement for the experimental modal test [1].

Table 3.3: Input parameters for the modal test experiment.

Item	Setting Value
Sweep Frequency Input	1 – 1000 Hz
Sweep Time	2 s
Amplitude	1.0 Vpp
Sampling Size	25.0 kS/s
Sampling	100 K sample (3 sweep for 1 triger)

Figure 3.13 shows the experimental equipment and arrangement for the analyses. For this test, A AFG3022C Function Generator was used to generate sweep frequency excitation from 1 to 1000 Hz which the vibration starts from the low frequency to high frequency and then amplified to 100 Vpp by a Low-PZT amplifier. Every sweep frequency, it takes 2s to complete the cycle. Table 3.3 shows input parameters for the modal experiment.

3.4.2 Nonlinear Vibro-Acoustic Modulation Test

The vibro-acoustic test was performed on the uncrack and crack plate to evaluate the effects of nonlinear acoustic modulation caused by nonlinearities inside the plate's particular crack. Specifically, the tests were performed to investigate the relation of crack edge behaviour to nonlinear acoustic modulation.

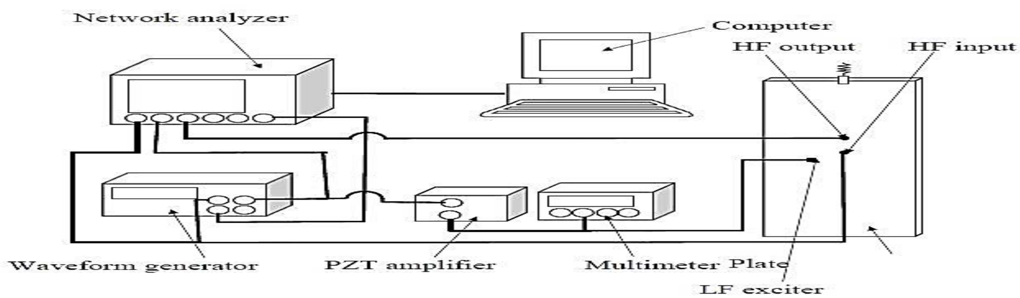

Figure 3.14: Experimental setup and arrangement for the conventional vibro-acoustic test [1].

Table 3.4: Input parameters for the vibro acoustic method experiment.

Item	Setting Value
High Frequency Input	60 kHz
Low Frequency Input	1 - 1000 Hz
Amplitude	1.0 Vpp
Sampling Size	25.0 kS/s
Temperature	25 - 39

From table 3.3, 60 kHz is chosen to introduce High Frequency (HF) input frequency because it is sensitive enough to detect small cracks and has a good ability to detect relative large cracks. While for Low Frequency (LW) input frequency, 1 - 1000 Hz is chosen refer to the modal test because 1st vibration mode is highly sensitive against the change of material stiffness. This vibration mode (natural frequency) is determined by using modal analysis. For the temperature, it must use higher than room temperature. At room temperature, the aluminium plate exhibits basically small deflection random vibration while at the higher temperature, the plate shows a decreased stiffness with such temperature rise through having higher deflection random vibration. The amplitude of high- and low-frequency excitation was equal to 1 and 100 Vpp, respectively. The “HF output” piezo-ceramic transducer was used to obtain the responses. The excitation signals were generated by using AFG3022C Function Generator. A schematic diagram illustrating the experimental set-up used in nonlinear acoustics tests is given in Figure 3.14. Table 3.4 shows input parameters for the vibro-acoustic experiment.

3.4 MATLAB

MATLAB or what we call Matrix Laboratory is a program for analyzing and computing numerical data, and MATLAB is also an advanced mathematical programming language, formed on the basis of thinking that uses matrix properties and form. MATHLAB is the programming language developed by The Mathwork Inc. which comes with different functions and characteristics of other pre-existing programming languages such as Delphi, Basic and C ++. It works for having various category of math function on a series of values. They basically consider various values for their graphical analysis. So that required level of representation is performed to the users. It is an automated tool performs various categories of graphs.

CHAPTER 4

RESULTS AND ANALYSIS

4.0 Introduction

In this chapter, we will show the result and discuss the result that has been got from the experiment procedure. The result is represented in table and graph of the amplitude-frequency domain from the uncrack and crack modal test, sidebands, modulation intensity (R-value) and determine the relation between R-value at different temperature.

4.1 Modal Test

Based on the modal test performed for uncrack and crack plate, the data that have been collected were analysed to obtain the result and discussion on finding. Uncrack plate data for the modal test are represented in Figure 4.1 respectively.

4.1.1 Result for Uncrack Modal Test

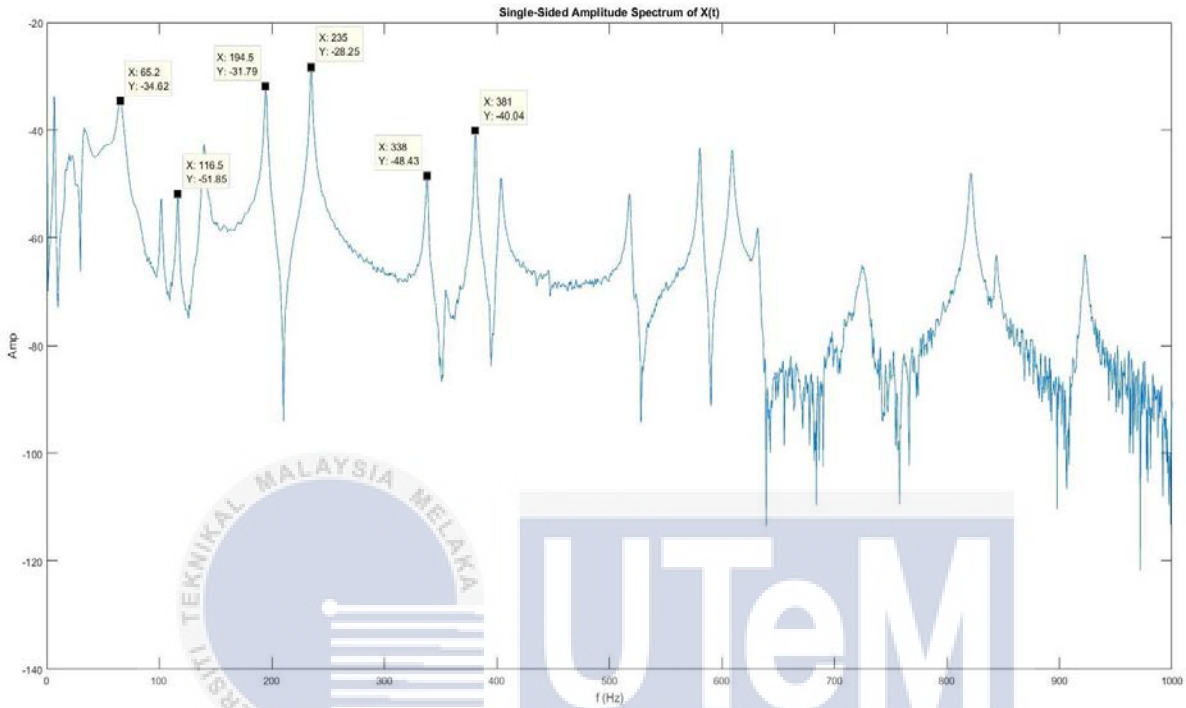

Figure 4.1: The graph of Amplitude (Amp) Versus Frequency (Hz) for Modal Test of Uncrack Aluminium Plate

Referring to the graph in Figure 4.1 above, it is represented the result from a modal test for uncrack plate experiment. Six of the highest frequency were selected to be implemented to the next non-linear vibroacoustic. The peak that has been selected based on the previous study of vibroacoustic. The value of the uncrack for the first six amplitude is 65.2 Hz, 116.5 Hz, 194.5 Hz, 235 Hz, 338 Hz and 381 Hz respectively.

4.1.2 Result for Crack Modal Test

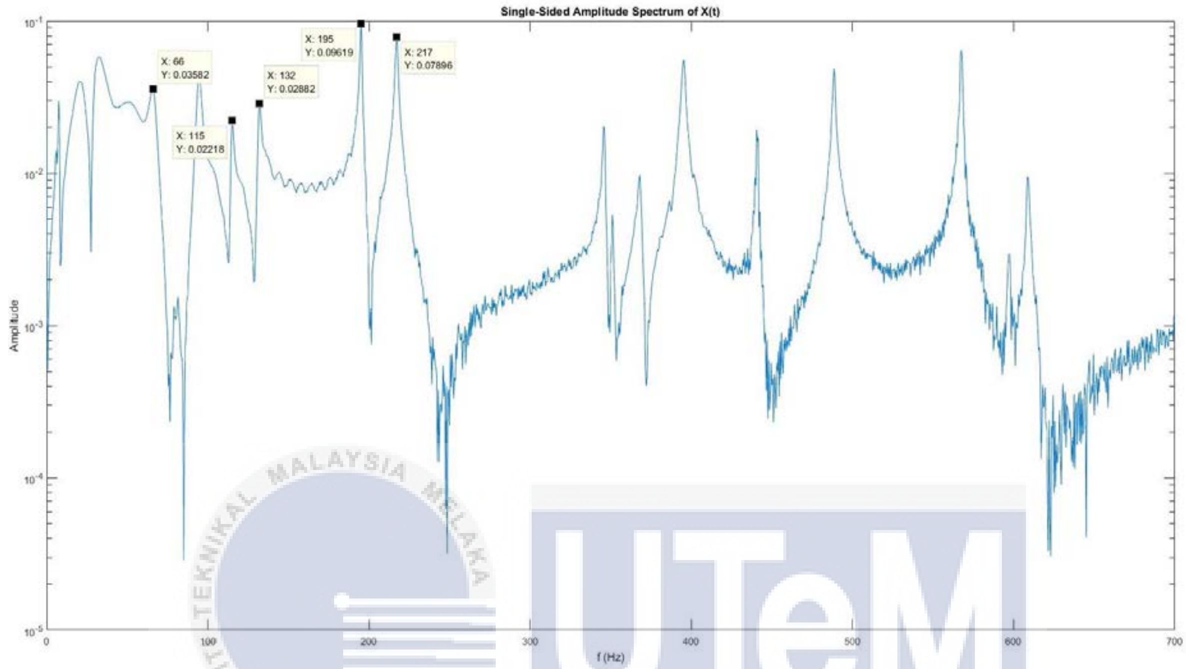

Figure 4.2: The graph of Amplitude (Amp) Versus Frequency (Hz) for Modal Test of Crack Aluminium Plate.

Referring to the graph in Figure 4.2 above, it is represented the result from a modal test for crack plate experiment. Five of the highest frequency were selected to be implemented to the next non-linear vibroacoustic. The peak that has been selected based on the previous study of vibroacoustic. The value of the crack for the first six amplitude is 66 Hz, 115 Hz, 132 Hz, 195 Hz and 217 Hz respectively.

4.2 Vibro Acoustic Test

4.2.1 Result for Uncrack Vibro acoustic Test

The vibro-acoustic method had been conducted on the un-cracked and cracked of the aluminium plate which has cut on the center with dimension 1.5mm x 4mm. Five modes were analysis with the investigation on High frequency and Low frequency introduce to present the waveform. After doing the experiment procedures in the previous chapter, the results are obtained after converted the amplitude-time domain data to the amplitude frequency domain using MATLAB. From these result, the generation of sidebands that represents the nonlinear effected can be observed. The result for each frequency mode 1, 2 and 3 of the uncrack plate shown in graph Amplitude frequency domain Figure 4.2, Figure 4.3, Figure 4.4, Figure 4.5, Figure 4.6, Figure 4.7, Figure 4.8 and Figure 4.9 respectively.

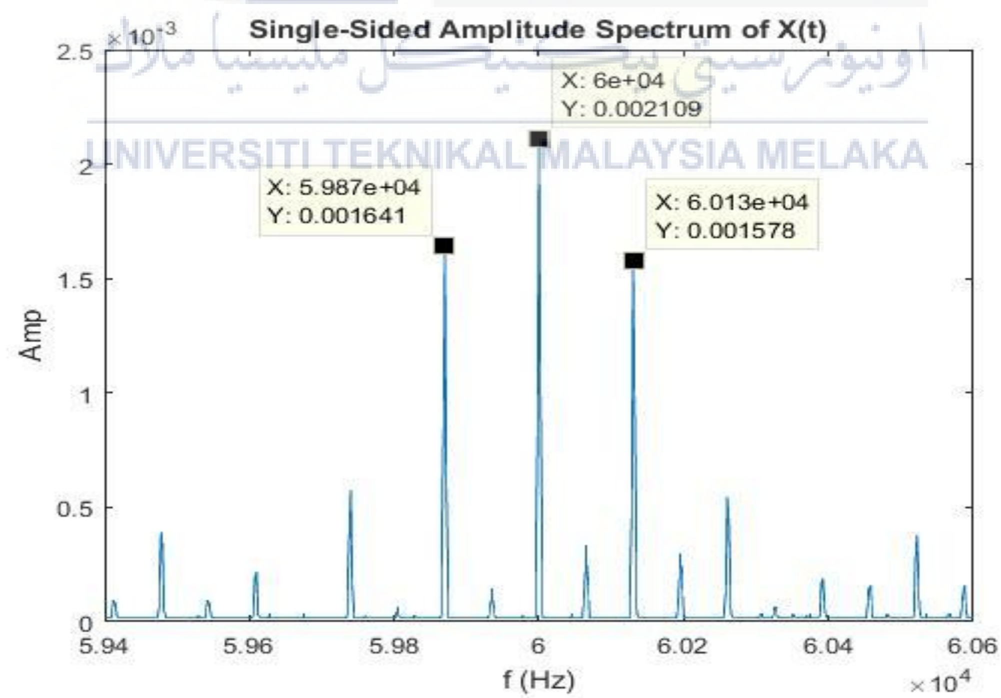

Figure 4.3: Amplitude-frequency domain for aluminium plate at 25°C with 1st vibration mode.

Figure 4.2 shows the amplitude-frequency domain for aluminium plate at 25˚C with 1st vibration mode. From the graph, there is only one pick of amplitude which is at 60 kHz. The amplitude of frequency at 60 kHz is 0.002109 dB with two sidebands at the first left and right is 0.001641 dB and 0.001578 dB.

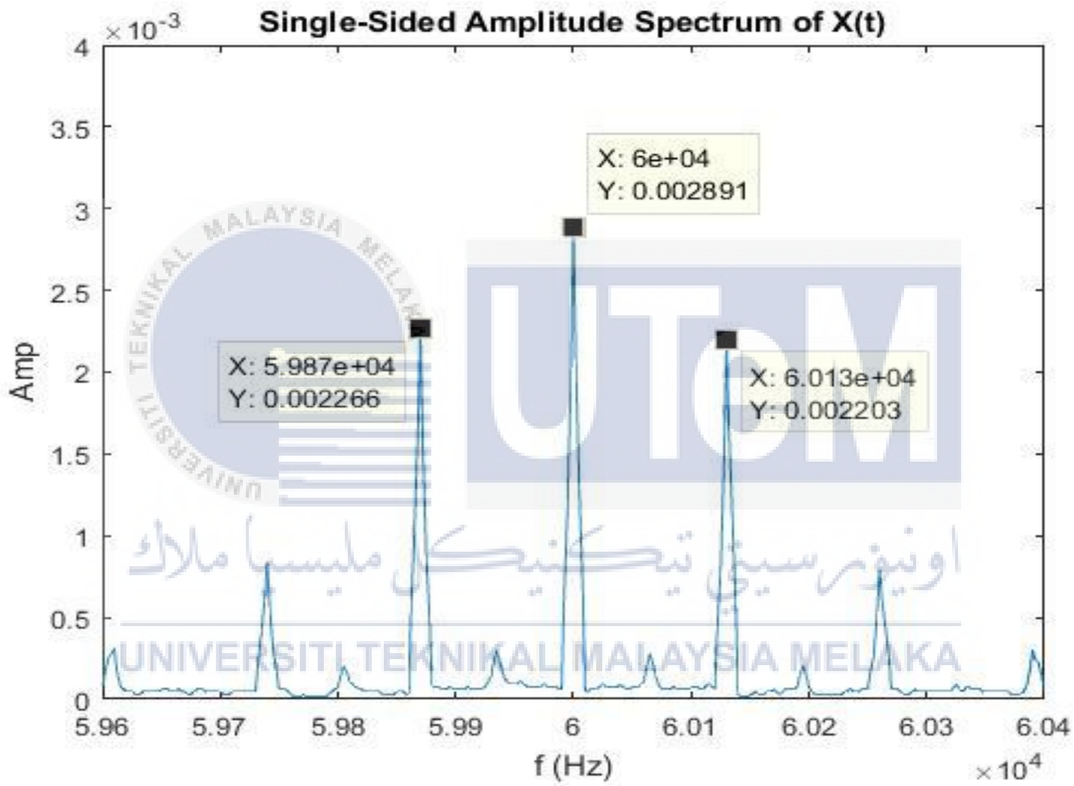

Figure 4.4: Amplitude-frequency domain for aluminium plate at 27˚C with 1st vibration mode.

Figure 4.3 shows the amplitude-frequency domain for aluminium plate at 25˚C with 1st vibration mode. From the graph, there is only one pick of amplitude which is at 60 kHz. The amplitude of frequency at 60 kHz is 0.002891 dB with two sidebands at the first left and right is 0.002266 dB and 0.002203 dB.

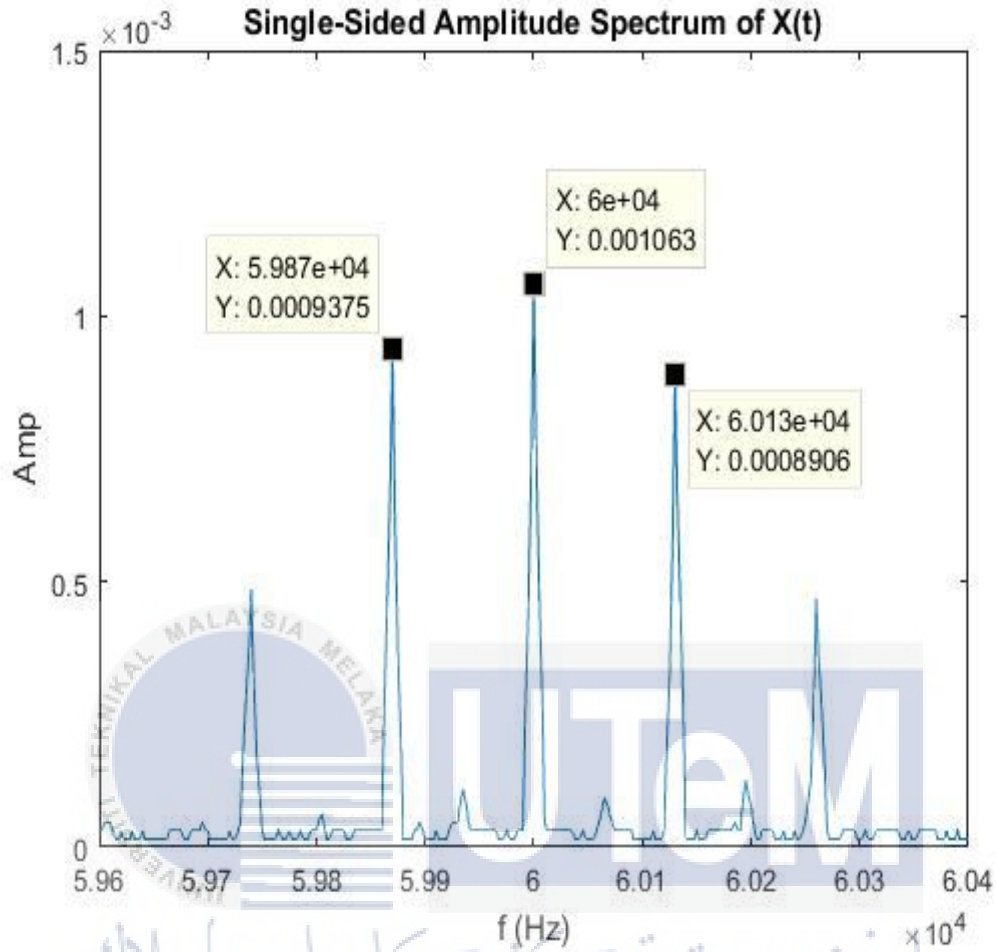

Figure 4.5: Amplitude-frequency domain for aluminium plate at 29˚C with 1st vibration mode.

Figure 4.4 shows the amplitude-frequency domain for aluminium plate at 29˚C with 1st vibration mode. From the graph, there is only one pick of amplitude which is at 60 kHz. The amplitude of frequency at 60 kHz is 0.001063 dB with two sidebands at the first left and right is 0.0009375 dB and 0.0008906 dB.

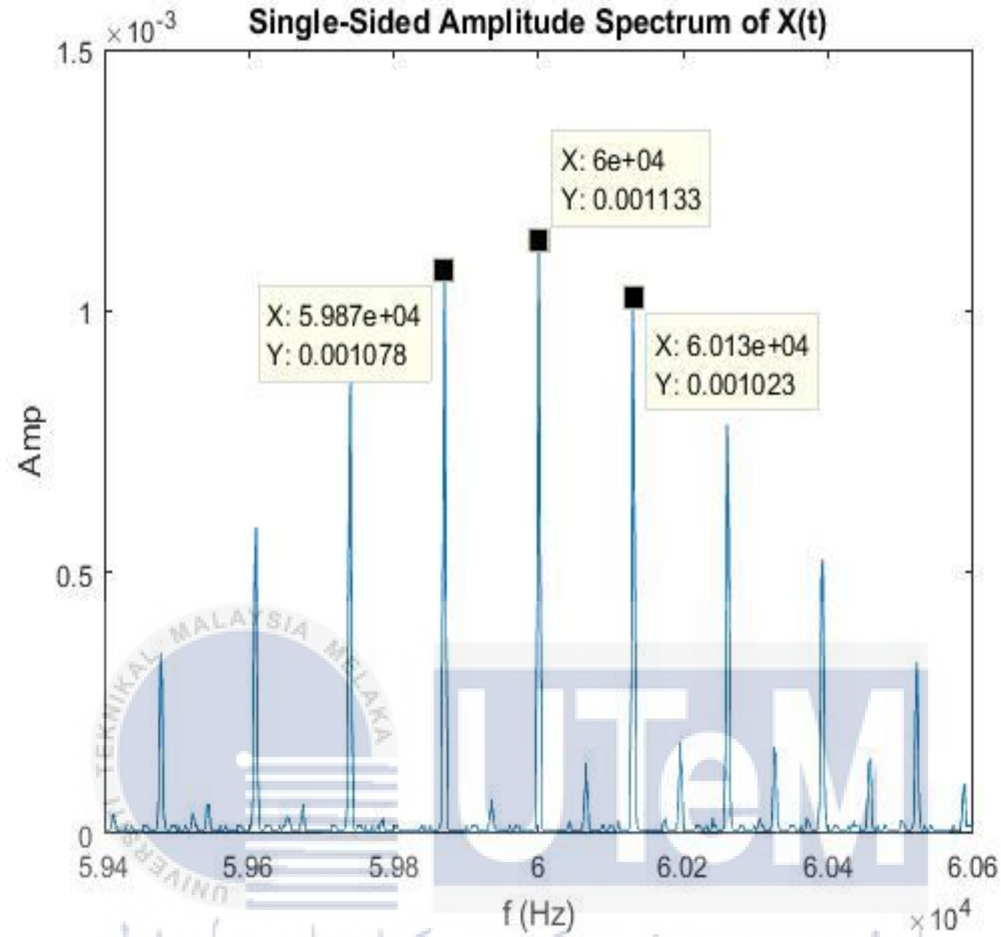

Figure 4.6: Amplitude-frequency domain for aluminium plate at 31˚C with 1st vibration mode.

Figure 4.5 shows the amplitude-frequency domain for aluminium plate at 31˚C with 1st vibration mode. From the graph, there is only one pick of amplitude which is at 60 kHz. The amplitude of frequency at 60 kHz is 0.001133 dB with two sidebands at the first left and right is 0.001078 dB and 0.001023 dB.

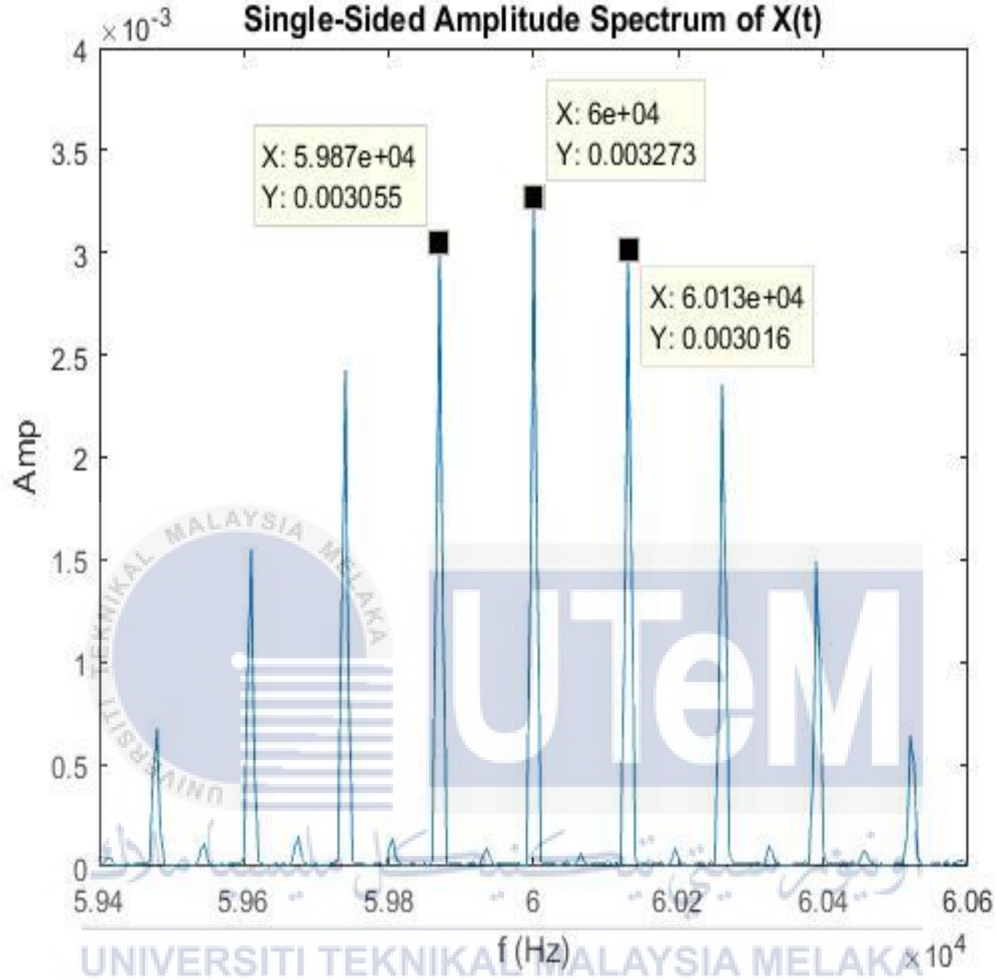

Figure 4.7: Amplitude-frequency domain for aluminium plate at 33˚C with 1st vibration mode.

Figure 4.6 shows the amplitude-frequency domain for aluminium plate at 33˚C with 1st vibration mode. From the graph, there is only one pick of amplitude which is at 60 kHz. The amplitude of frequency at 60 kHz is 0.003273 dB with two sidebands at the first left and right is 0.003055 dB and 0.003016 dB.

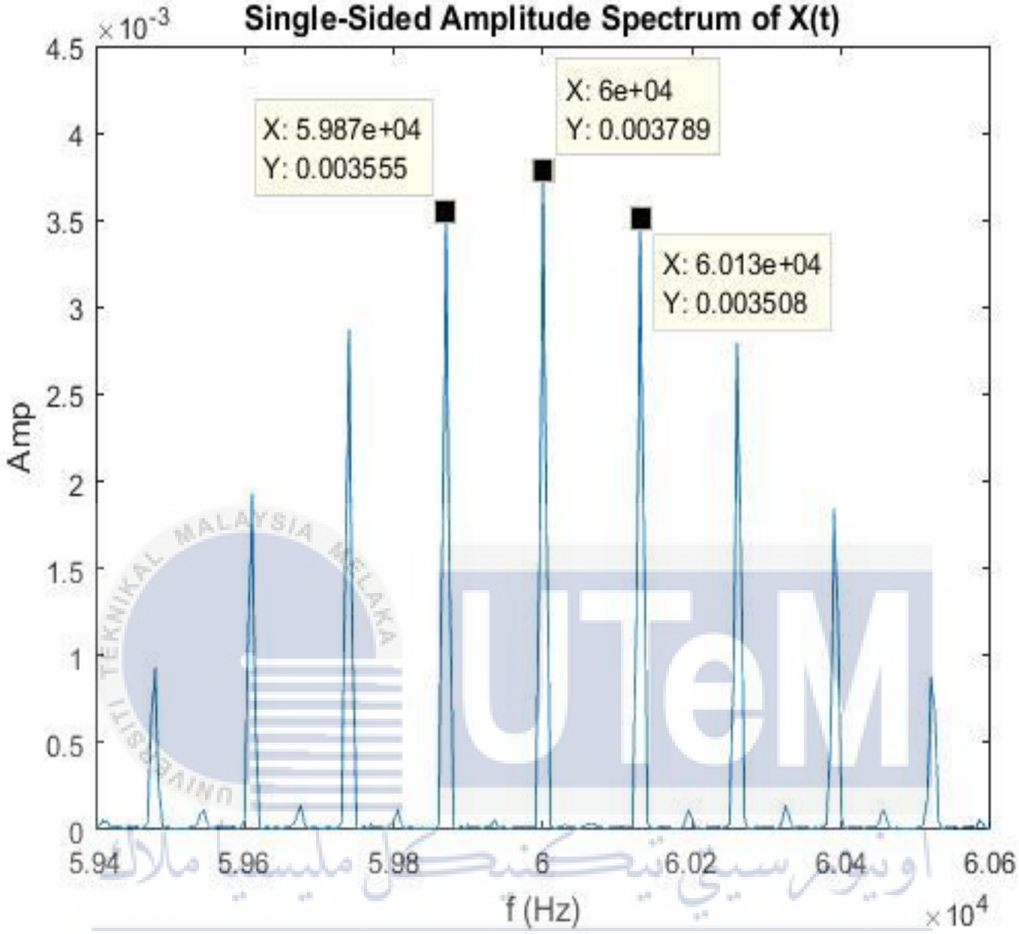

Figure 4.8: Amplitude-frequency domain for aluminium plate at 35˚C with 1st vibration mode.

Figure 4.7 shows the amplitude-frequency domain for aluminium plate at 35˚C with 1st vibration mode. From the graph, there is only one pick of amplitude which is at 60 kHz. The amplitude of frequency at 60 kHz is 0.003789 dB with two sidebands at the first left and right is 0.003555 dB and 0.003508 dB.

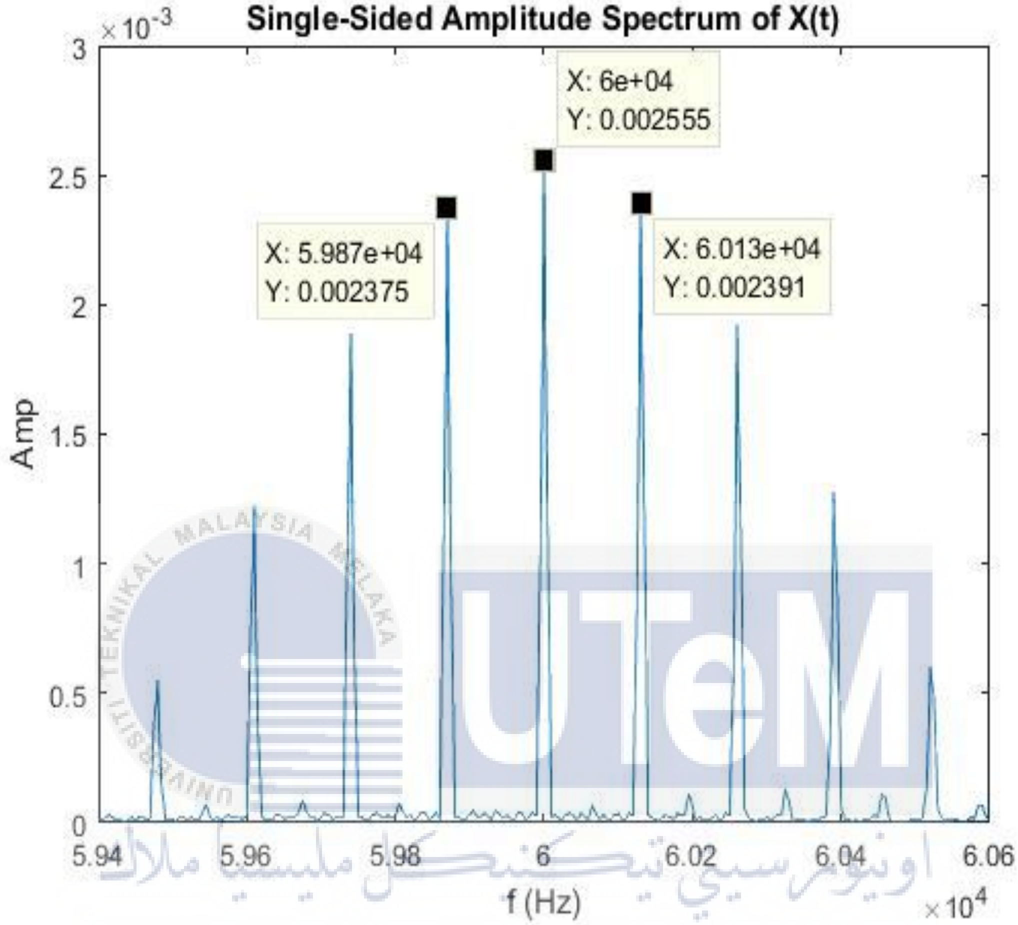

Figure 4.9: Amplitude-frequency domain for aluminium plate at 37˚C with 1st vibration mode.

Figure 4.8 shows the amplitude-frequency domain for aluminium plate at 37˚C with 1st vibration mode. From the graph, there is only one pick of amplitude which is at 60 kHz. The amplitude of frequency at 60 kHz is 0.002555 dB with two sidebands at the first left and right is 0.002395 dB and 0.002391 dB.

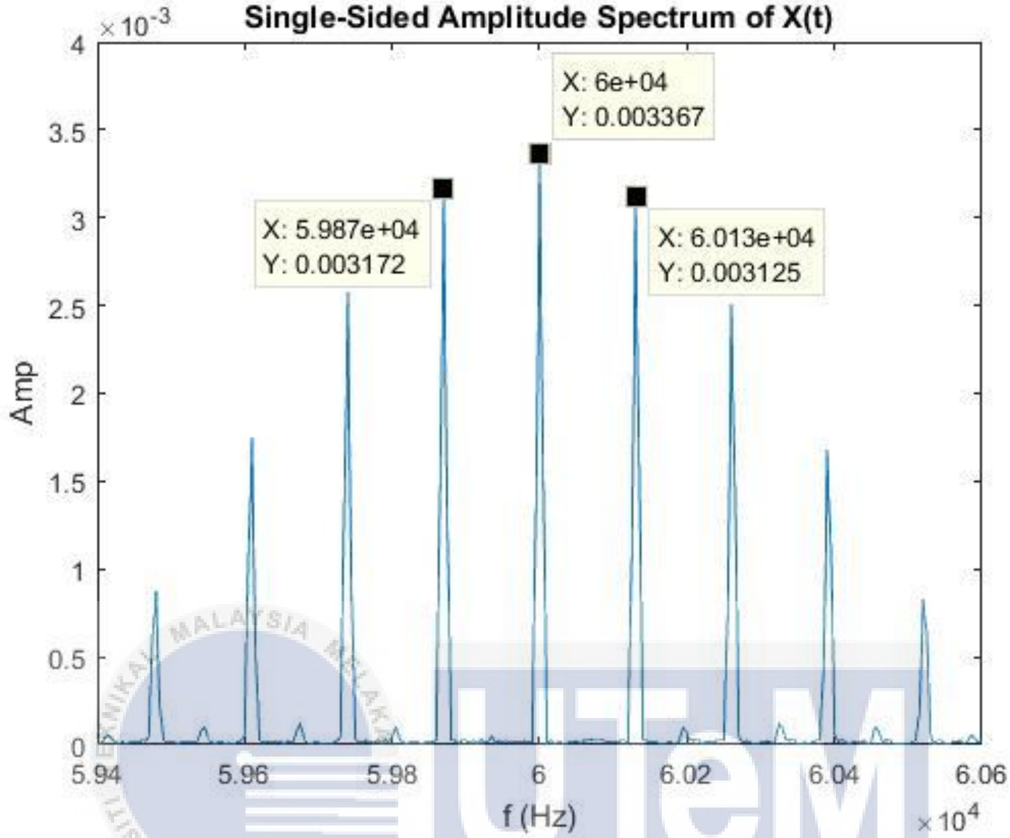

Figure 4.10: Amplitude-frequency domain for aluminium plate at 39˚C with 1st vibration mode.

Figure 4.9 shows the amplitude-frequency domain for aluminium plate at 39˚C with 1st vibration mode. From the graph, there is only one pick of amplitude which is at 60 kHz. The amplitude of frequency at 60 kHz is 0.003367 dB with two sidebands at the first left and right is 0.003172 dB and 0.003125 dB.

From the results, the data can be conclude that most of the frequency response function at high frequency 60 kHz with different of temperature is very small value. It is easy to identify the difference among the graph. The graphs of amplitude-frequency domain were plotted. Then, the analysis of nonlinear modulation intensity effect were performed. Sidebands are band of higher frequency than and lower than a carrier frequency resulting from an amplitude modulation mechanism. Amplitude modulation is an effect of low-frequency signal against amplitude variation of the high carrier frequency signal. The modulated signal will appear in the form of a sideband with interval between the sideband is equal to the low frequency signal. Therefore the effect of modulation is caused by the interaction of the low frequency and high frequency excitation. Figure 4.2 until Figure 4.9 show the amplitude-frequency domain for heated plate with 1st vibration mode. Those figures show the heated plate that have produce modulation effects when excited with the 1st vibration modes because the sideband is appears on the graphs. Therefore, there is interaction between high frequency and low vibration frequency when propagate through the heated aluminium plate.

The intensity of the nonlinear acoustic, R value can be obtain by using the formula:

$$R = \frac{A1+A2}{A0} \tag{1}$$

$A_{1,2}$: Amplitude of 1st and 2nd side band

A_0 : Amplitude of high frequency

R value is used to plot a graph against temperature change, ΔT. From this graph, the relationship of the heat capacity and nonlinear acoustic effect can be determined.

Table 4.1: Sideband amplitude and Modulation Intensity, R at different temperature for 1st frequency mode (65.2 Hz).

N	Temperature (˚C)	A0	A1	A2	R-value (with shaker)	R-value(without shaker)
1	no heating	0.004742	0.0033830	0.0034920	1.44981	0
2	25	0.002109	0.0016410	0.0015780	1.52632	0.07651
3	27	0.002891	0.0022660	0.0022030	1.54583	0.09602
4	29	0.001063	0.0009075	0.0008906	1.69153	0.24172
5	31	0.001133	0.0009690	0.0010190	1.75463	0.30482
6	33	0.003273	0.0030550	0.0030160	1.85487	0.40506
7	35	0.003789	0.0035550	0.0035080	1.86408	0.41427
8	37	0.002555	0.0023950	0.0023910	1.87319	0.42338
9	39	0.003367	0.0031720	0.0031250	1.89999	0.45018

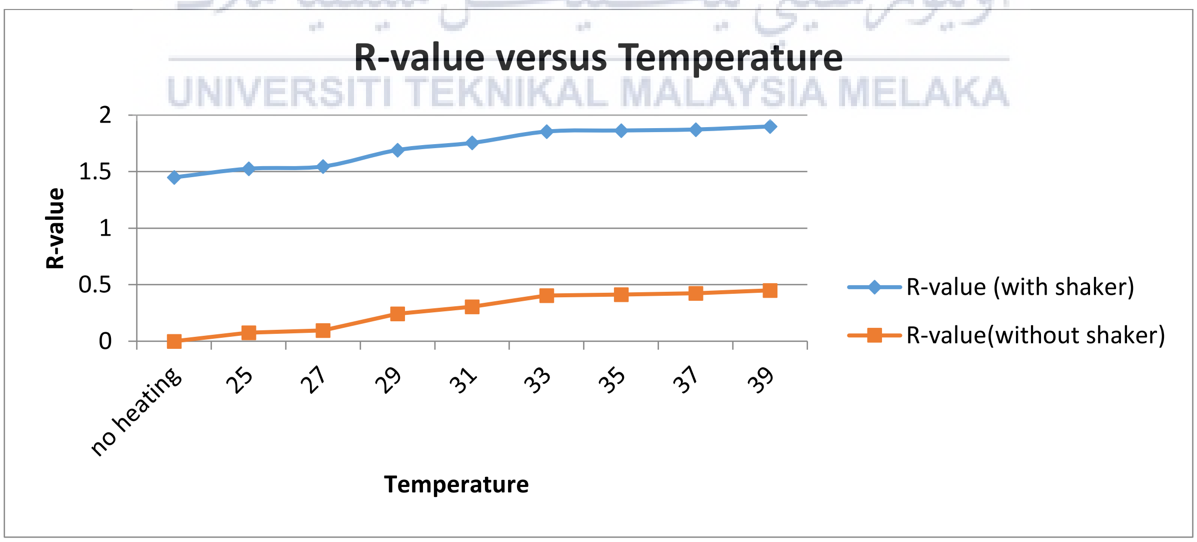

Figure 4.11: Comparison of R-value by using shaker and without shaker versus Temperature at 1st frequency mode (65.2 Hz).

Table 4.2: Sideband amplitude and Modulation Intensity, R at different temperature for 2nd frequency mode (116.5 Hz).

N	Temperature (˚C)	A0	A1	A2	R-value (with shaker)	R-value(without shaker)
1	no heating	0.0015080	0.0009063	0.0009297	1.21751	0
2	25	0.0032200	0.0022170	0.0022830	1.39752	0.18001
3	27	0.0037530	0.0027090	0.0027890	1.46496	0.24745
4	29	0.0049620	0.0036660	0.0037620	1.49698	0.27947
5	31	0.0051810	0.0038840	0.0039940	1.52056	0.30305
6	33	0.0019280	0.0015480	0.0014530	1.55654	0.33903
7	35	0.0036840	0.0028630	0.0029440	1.57628	0.35877
8	37	0.0012660	0.0010220	0.0010470	1.63428	0.41677
9	39	0.0008945	0.0008297	0.0007719	1.79049	0.57298

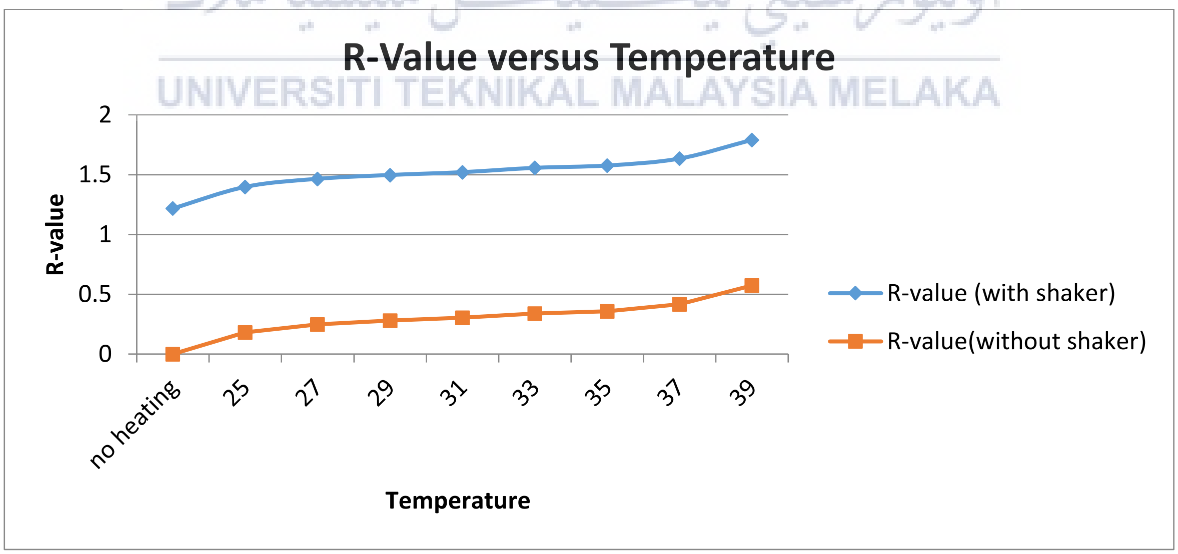

Figure 4.12: Comparison of R-value by using shaker and without shaker versus Temperature at 2nd frequency mode (116.5 Hz).

Table 4.3: Sideband amplitude and Modulation Intensity, R at different temperature for 3rd frequency mode (194.5 Hz).

N	Temperature (˚C)	A0	A1	A2	R-value (with shaker)	R-value(without shaker)
1	no heating	0.0025940	0.0006539	0.0005711	0.47224	0
2	25	0.0005345	0.0002694	0.0003098	1.08363	0.61139
3	27	0.0023440	0.0013400	0.0013390	1.14292	0.67068
4	29	0.0010780	0.0006681	0.0006181	1.19314	0.72090
5	31	0.0013940	0.0008156	0.0009734	1.28338	0.81114
6	33	0.0012500	0.0007131	0.0008941	1.28576	0.81352
7	35	0.0016230	0.0009878	0.0011450	1.31411	0.84187
8	37	0.0006008	0.0003566	0.0004405	1.32673	0.85449
9	39	0.0007128	0.0004417	0.0005512	1.39296	0.92072

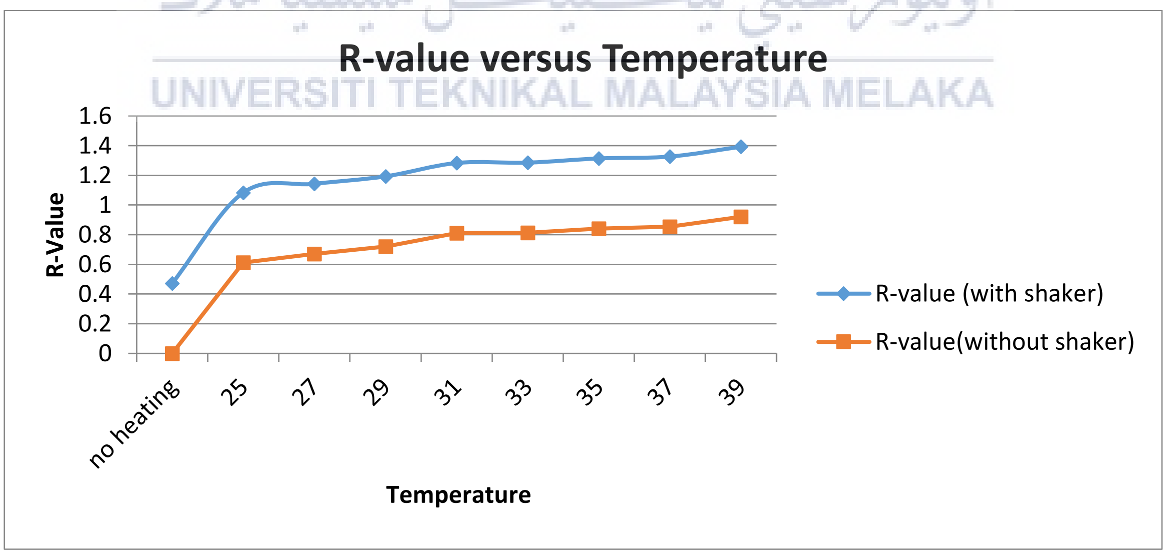

Figure 4.13: Comparison of R-value by using shaker and without shaker versus Temperature at 3rd frequency mode (194.5 Hz).

Table 4.4: Sideband amplitude and Modulation Intensity, R at different temperature for 4th frequency mode (235 Hz).

N	Temperature (˚C)	A0	A1	A2	R-value (with shaker)	R-value(without shaker)
1	no heating	0.0030860	0.0012810	0.0012970	0.83539	0
2	25	0.0079140	0.0055860	0.0056250	1.41660	0.58121
3	27	0.0050160	0.0036090	0.0036280	1.44278	0.60739
4	29	0.0017340	0.0014610	0.0014610	1.68512	0.84973
5	31	0.0007578	0.0006641	0.0006563	1.74202	0.90663
6	33	0.0022310	0.0019390	0.0019530	1.74451	0.90912
7	35	0.0028340	0.0025690	0.0025880	1.81969	0.98430
8	37	0.0028340	0.0025970	0.0026160	1.83945	1.00406
9	39	0.0022660	0.0021000	0.0021160	1.86055	1.02516

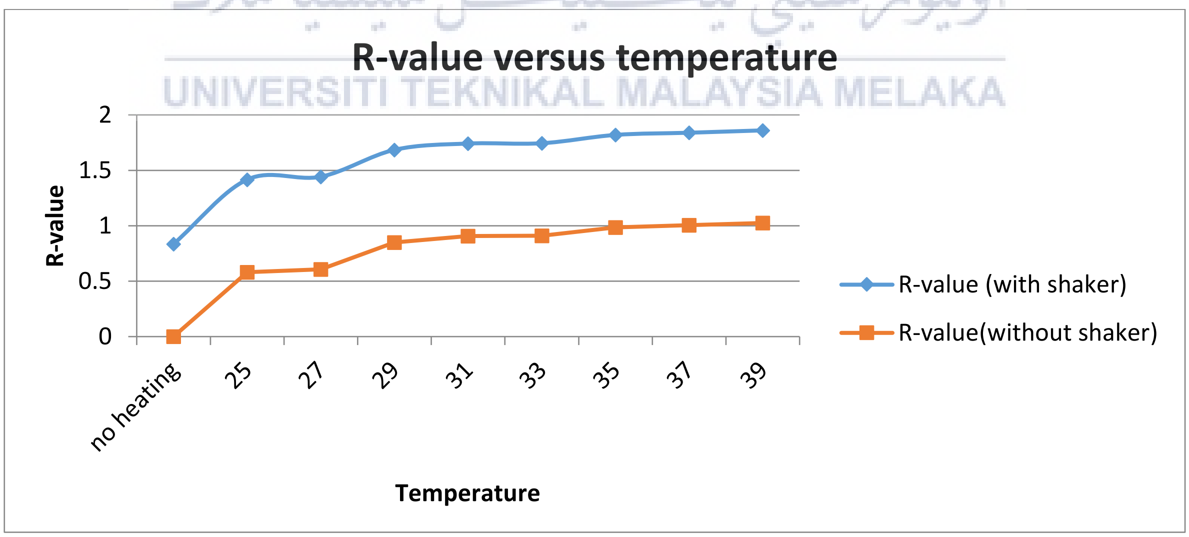

Figure 4.14: Comparison of R-value by using shaker and without shaker versus Temperature at 4th frequency mode (235 Hz).

Table 4.5: Sideband amplitude and Modulation Intensity, R at different temperature for 5^{th} frequency mode (338 Hz).

N	Temperature (˚C)	A0	A1	A2	R-value (with shaker)	R-value(without shaker)
1	No heating	0.0033420	0.0002555	0.0002875	0.162478	0
2	25	0.0009000	0.0004709	0.0004634	1.038110	0.875632
3	27	0.0010150	0.0005887	0.0005812	1.152610	0.990132
4	29	0.0011230	0.0006597	0.0006428	1.159840	0.997362
5	31	0.0003789	0.0002231	0.0002186	1.165740	1.003262
6	33	0.0003783	0.0002322	0.0002269	1.213590	1.051112
7	35	0.0009289	0.0006367	0.0005352	1.261384	1.098906
8	37	0.0005520	0.0003698	0.0003623	1.326268	1.163790
9	39	0.0003680	0.0002891	0.0002414	1.441576	1.279098

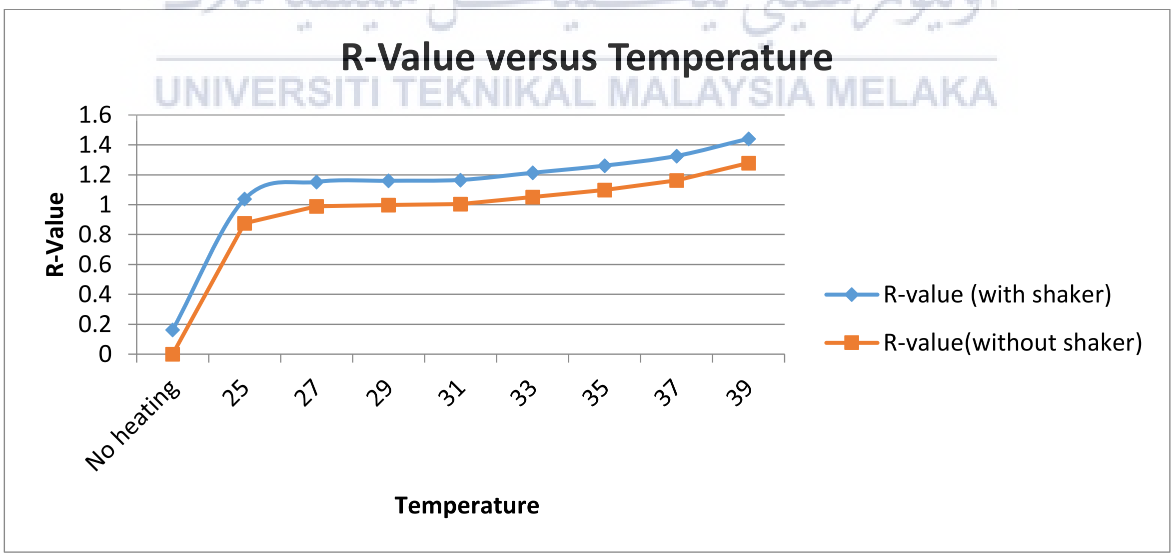

Figure 4.15: Comparison of R-value by using shaker and without shaker versus Temperature at 5^{th} frequency mode (338 Hz).

Table 4.6: Sideband amplitude and Modulation Intensity, R at different temperature for 6th frequency mode (381 Hz).

N	Temperature (˚C)	A0	A1	A2	R-value (with shaker)	R-value(without shaker)
1	No heating	0.0032160	0.0003867	0.0003938	0.24269	0
2	25	0.0028790	0.0011960	0.0011850	0.82702	0.584330
3	27	0.0032200	0.0014230	0.0013880	0.87298	0.630290
4	29	0.0015300	0.0008659	0.0008391	1.11438	0.871690
5	31	0.0009631	0.0006053	0.0005777	1.22833	0.985640
6	33	0.0018390	0.0011630	0.0011040	1.23274	0.980584
7	35	0.0009294	0.0006047	0.0005716	1.26566	1.022970
8	37	0.0004500	0.0003609	0.0003297	1.53467	1.291980
9	39	0.0009422	0.0008883	0.0008617	1.85736	1.614670

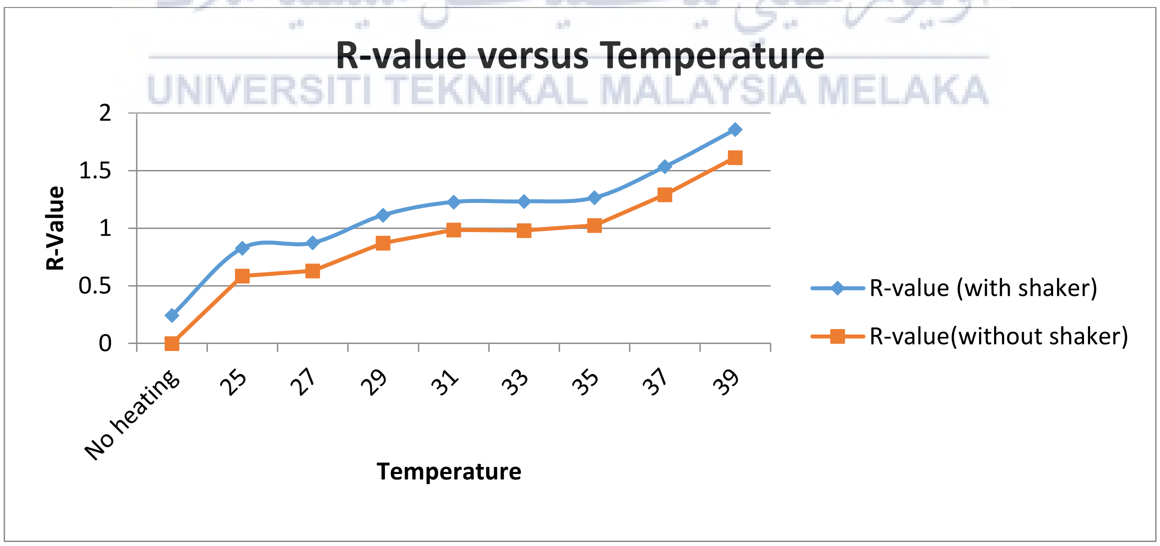

Figure 4.16: Comparison of R-value by using shaker and without shaker versus Temperature at 6th frequency mode (381 Hz).

The value of R from Table 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6 that was used to plot a graph against the increasing of temperature as shown in figure 4.7. So, the relationship between R-value (without shaker) and the temperature can be observed clearly by comparing with six different sidebands.

4.2.1.1 Determine the relation between R-value and Different Temperature for uncrack plate

By combining both experimental results presented in the Modal test and non-linear vibro acoustic test, The R-value of without shaker can be tabulated into a graph. In order to ensure the reader easily understand the finding, the graph provides shows the relationship of R-value with different temperature by different frequency mode.

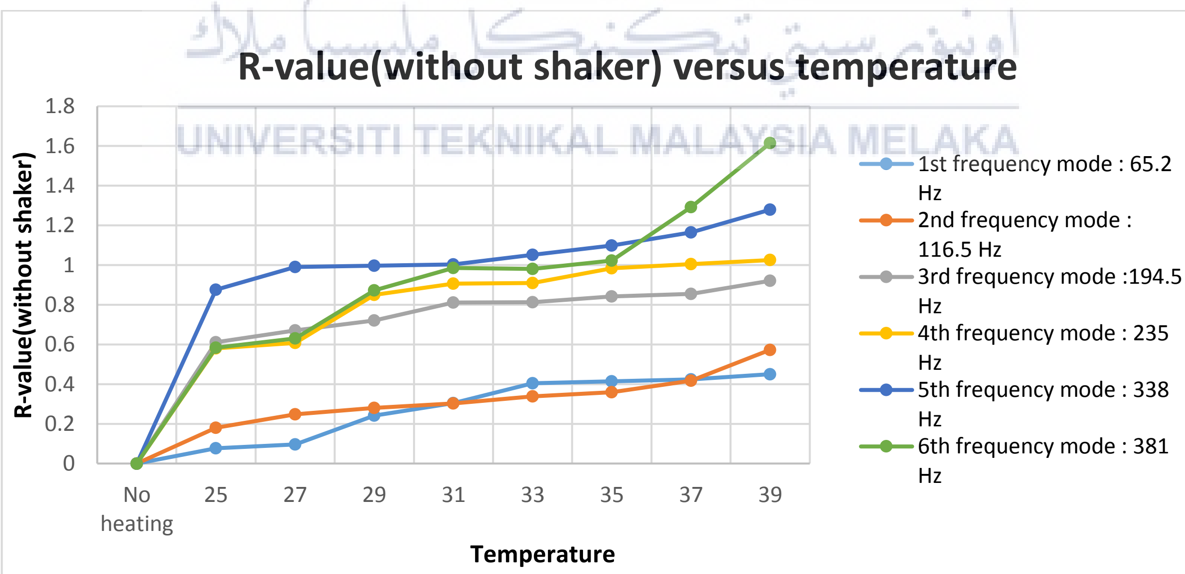

Figure 4.17: R value (without shaker) versus Temperature for different frequency mode.

The modulation intensity, R was used to quantify the level of vibroacoustic effect. From the previous study for the uncrack detection using vibroacoustic method, the value of R increased when the temperature is increased. It meant that the nonlinear acoustic wave modulation intensity, R is directly proportional to the increase of temperature. The result was very different for the increase of temperature as shown in Figure 4.7. For the 1^{st} and 2^{nd} frequency mode, the value of R is change at temperature 31˚C and change again at 37˚C. For the 3^{rd}, 4^{th} and 6^{th} frequency mode, at the initial temperature, the R value is mostly the same and it changes starting on temperature 27˚C above. While at 5^{th} frequency mode, the R-value is higher at 25˚C until 35˚C. Through this experiment, it showed that the temperature of the plate affects the value of nonlinear acoustic wave modulation intensity but not affect the different frequency mode. This situation might occur because there were some errors and problems in the experiment setup. These errors will be discussed in the next chapter.

Based on the results from Table 4.1 to Table 4.6, there is clear evidence that the effects of amplitude wave modulation are closely related to temperature field changes. The relationship between R-value and temperature indicates that wave amplitude modulation is strongly influenced by heat and electrostatic mechanisms. However, further investigation is needed to identify the contribution mechanism to the wave modulation effect. This relationship shows a clear connection between vibration and acoustic modulation and heat field. Since the plates are always excited, the cracks will not grow but the parameters change the only temperature. Therefore, the value of R is observed with temperature rise shown in Fig. 4.11 to Figure 4.17.

4.2.2 Result for Crack Vibro acoustic Test

The vibro-acoustic method had been conducted on the cracked of the aluminium plate with has cut on the center with dimension 1.5 mm x 4 mm and fatigue crack with length 20 mm. Five modes were analysis with the investigation on High frequency and Low frequency introduce to present the waveform. After doing the experiment procedures in the previous chapter, the results are obtained after converted the amplitude-time domain data to the amplitude frequency domain using MATLAB. From these result, the generation of sidebands that represents the nonlinear effected can be observed.

Table 4.7: Sideband amplitude and Modulation Intensity, R at different temperature for 1st frequency mode (66 Hz).

N	Temperature (°C)	A0	A1	A2	R-value (with shaker)	R-value(without shaker)
1	no heating	0.0033440	0.0024690	0.0024060	1.45783	0
2	25	0.0056870	0.0043130	0.0042190	1.50026	0.04243
3	27	0.0037810	0.0029840	0.0032190	1.63243	0.17460
4	29	0.0004281	0.0003375	0.0003734	1.66059	0.20276
5	31	0.0016020	0.0014920	0.0015000	1.85759	0.39976
6	33	0.0031800	0.0029060	0.0030080	1.85975	0.40192
7	35	0.0018830	0.0017340	0.0017810	1.86670	0.40887
8	37	0.0002391	0.0002297	0.0002203	1.88206	0.42423
9	39	0.0032890	0.0030550	0.0031480	1.88598	0.42815

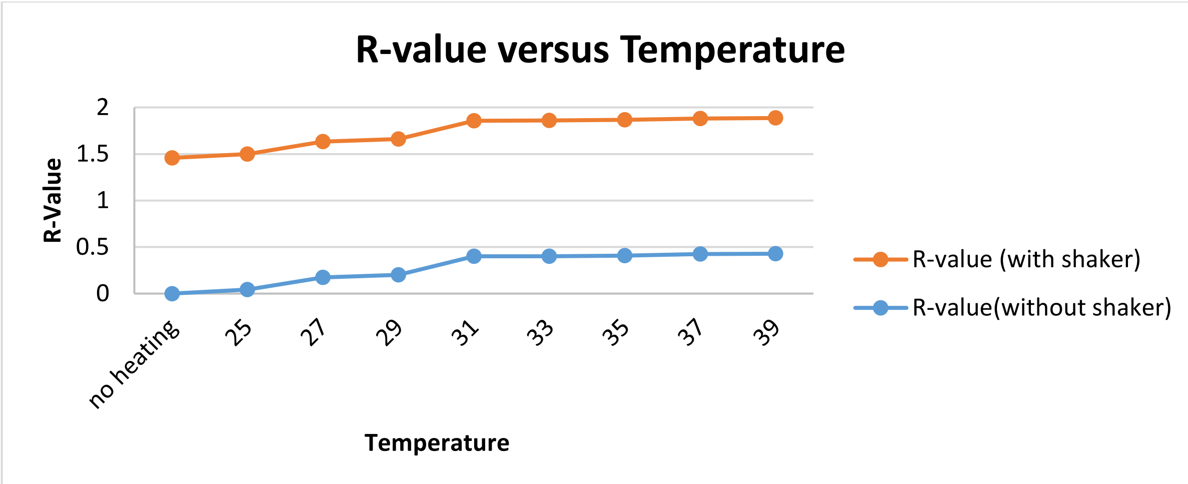

Figure 4.18: Comparison of R-value by using shaker and without shaker versus Temperature at 1st frequency mode (66 Hz).

Table 4.8: Sideband amplitude and Modulation Intensity, R at different temperature for 2nd frequency mode (115 Hz).

N	Temperature (˚C)	A0	A1	A2	R-value (with shaker)	R-value(without shaker)
1	no heating	0.002828	0.002188	0.002234	1.56365	0
2	25	0.004406	0.003617	0.003687	1.65774	0.09409
3	27	0.002516	0.002117	0.002148	1.69515	0.1315
4	29	0.006781	0.005789	0.005961	1.73278	0.16913
5	31	0.00368	0.003211	0.003312	1.77255	0.2089
6	33	0.002516	0.00225	0.002281	1.80087	0.23722
7	35	0.007234	0.006711	0.006727	1.85762	0.29397
8	37	0.007906	0.007203	0.007687	1.88338	0.31973
9	39	0.003523	0.00332	0.003383	1.90264	0.33899

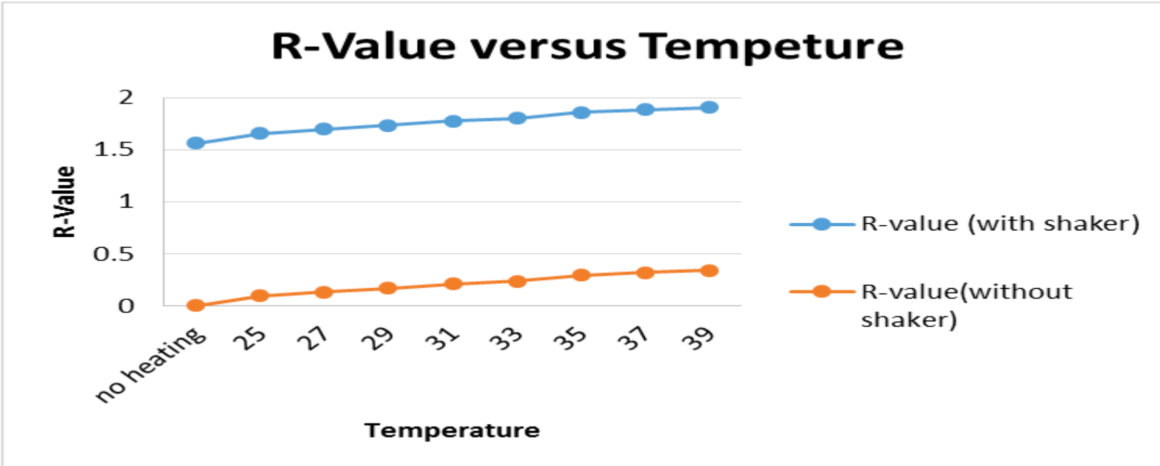

Figure 4.19: Comparison of R-value by using shaker and without shaker versus Temperature at 2nd frequency mode (115 Hz).

Table 4.9: Sideband amplitude and Modulation Intensity, R at different temperature for 3rd frequency mode (132 Hz).

N	Temperature (˚C)	A0	A1	A2	R-value (with shaker)	R-value(without shaker)
1	no heating	0.0002402	0.0001652	0.0001308	1.22228	0
2	25	0.0100900	0.006142	0.0061520	1.23093	0.00865
3	27	0.0042470	0.002719	0.0025690	1.25251	0.03023
4	29	0.0063660	0.004066	0.0039970	1.26572	0.04344
5	31	0.0045840	0.002997	0.0029030	1.28709	0.06481
6	33	0.0046020	0.003106	0.0030230	1.33181	0.10953
7	35	0.0079280	0.005041	0.0058410	1.37260	0.15032
8	37	0.0070220	0.004823	0.0051110	1.41469	0.19241
9	39	0.0051840	0.003556	0.0039870	1.45505	0.23277

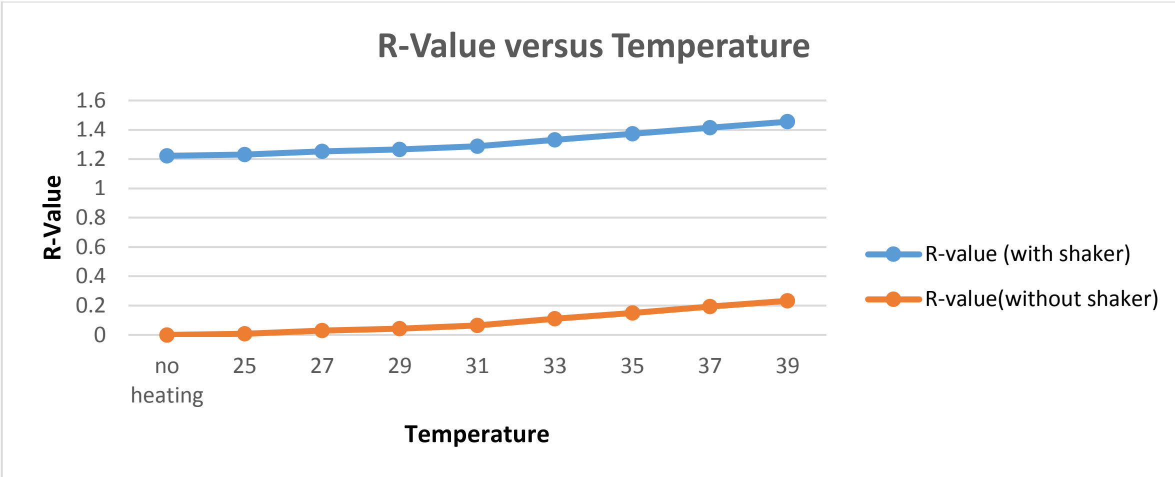

Figure 4.20: Comparison of R-value by using shaker and without shaker versus Temperature at 3rd frequency mode (132 Hz).

Table 4.10: Sideband amplitude and Modulation Intensity, R at different temperature for 4th frequency mode (195 Hz).

N	Temperature (˚C)	A0	A1	A2	R-value (with shaker)	R-value(without shaker)
1	no heating	0.002828	0.002188	0.002234	1.56365	0
2	25	0.004406	0.003617	0.003687	1.65774	0.09409
3	27	0.002516	0.002117	0.002148	1.69515	0.13150
4	29	0.006781	0.005789	0.005961	1.73278	0.16913
5	31	0.003680	0.003211	0.003312	1.77255	0.20890
6	33	0.002516	0.002250	0.002281	1.80087	0.23722
7	35	0.007234	0.006711	0.006727	1.85762	0.29397
8	37	0.007906	0.007203	0.007687	1.88338	0.31973
9	39	0.003523	0.003320	0.003383	1.90264	0.33899

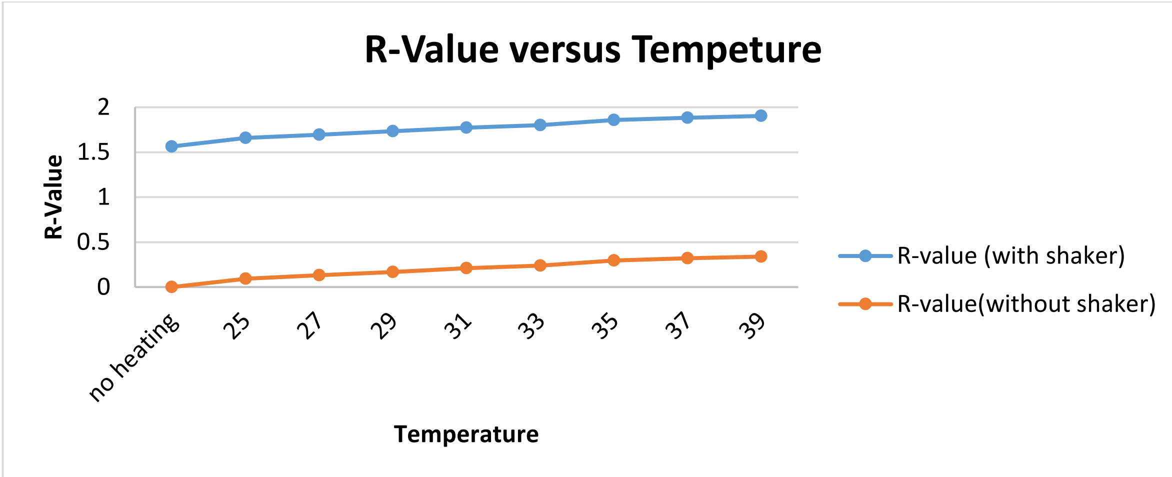

Figure 4.21: Comparison of R-value by using shaker and without shaker versus Temperature at 4th frequency mode (195 Hz).

Table 4.11: Sideband amplitude and Modulation Intensity, R at different temperature for 5th frequency mode (217 Hz).

N	Temperature (˚C)	A0	A1	A2	R-value (with shaker)	R-value(without shaker)
1	no heating	0.0108300	0.0065940	0.0070630	1.26103	0
2	25	0.0047970	0.0031250	0.0031330	1.30457	0.04354
3	27	0.0084220	0.0056330	0.0058130	1.35906	0.09803
4	29	0.0002034	0.0001494	0.0001503	1.47345	0.21242
5	31	0.0035340	0.0029000	0.0029620	1.65874	0.39771
6	33	0.0056870	0.0048120	0.0046870	1.67030	0.40927
7	35	0.0025560	0.0022810	0.0020780	1.70539	0.44436
8	37	0.0024090	0.0020840	0.0020840	1.73018	0.46915
9	39	0.0017610	0.0016090	0.0016450	1.84781	0.58678

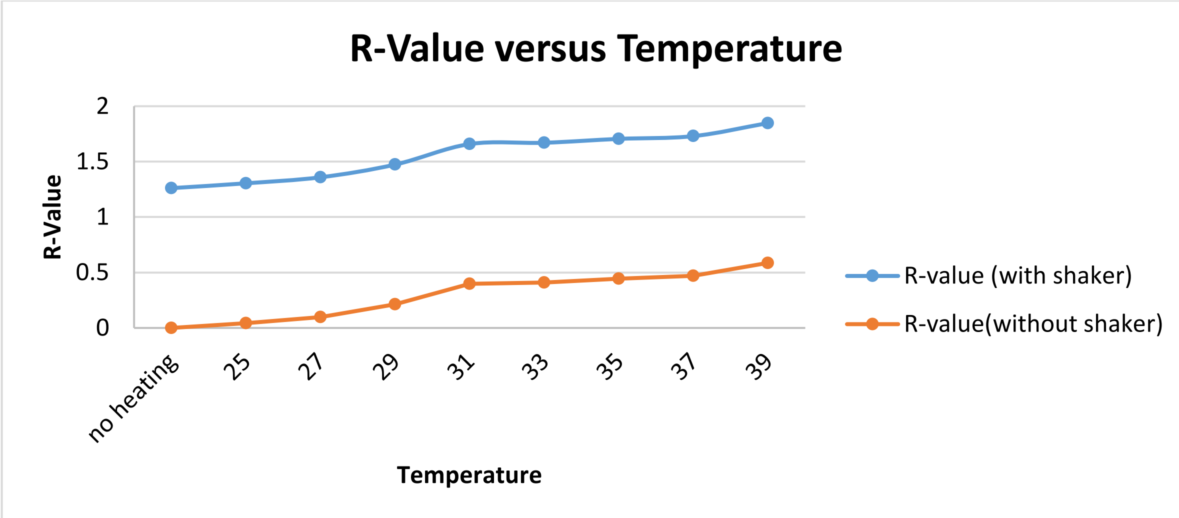

Figure 4.22: Comparison of R-value by using shaker and without shaker versus Temperature at 5th frequency mode (217 Hz).

The value of R from Table 4.6, 4.7, 4.8, 4.9 and 4.10 then was used to plot a graph against the increasing of temperature as shown in figure 4.20. So, the relationship between R-value (without shaker) and the temperature can be observed clearly by comparing with six different sidebands.

4.2.2.1 Determine the relation between R-value and Different Temperature for crack plate

By combining both experimental results presented in the Modal test and non-linear Vibro-acoustic test, The R-value of without shaker can be tabulated into a graph. In order to ensure the reader easily understand the finding, the graph provides shows with the relationship of R-value with different temperature by different frequency mode.

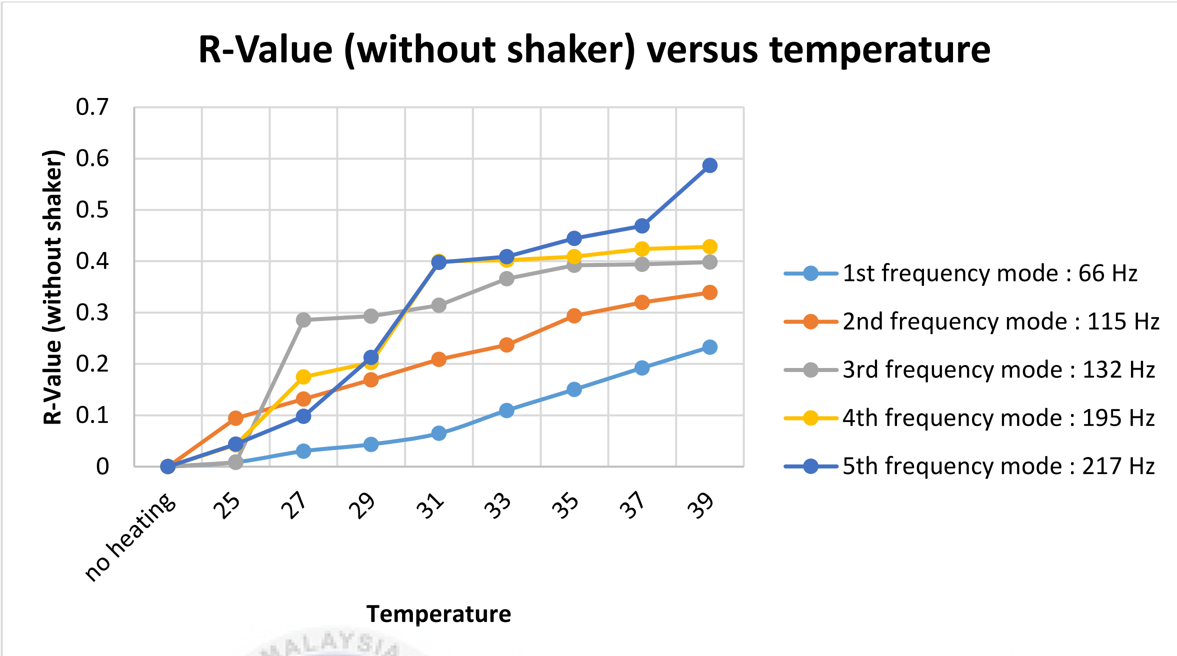

Figure 4.23: R value (without shaker) versus Temperature for different frequency mode.

The modulation intensity, R was used to quantify the level of vibro-acoustic effect. From the previous study for the uncrack detection using vibro-acoustic method, the value of R increased when the temperature is increased. It meant that the nonlinear acoustic wave modulation intensity, R is directly proportional to the increase of temperature. The figure shows results for the increase of R-value when increasing the temperature. The increase of R-value in the 1st frequency mode and the 2nd frequency mode at each temperature is mostly the same where the increase of R-value is not much compared to other modes. In the 3rd frequency mode, increased R-value more at temperatures of 25˚C to 27˚C. At temperature 27˚C and above, R-value increase is a bit like the 1st and 2nd frequency modes. At temperature 29˚C to 31˚C, the R-value of 4th and 5th frequency mode is the same in the graph and start to slightly different the increase of R-value after temperature 31˚C and above. Through this experiment, it showed that the temperature of the plate affects the value of nonlinear acoustic wave modulation intensity but not affect the different frequency mode. This situation might occur because there were some errors and problems in the experiment setup. These errors will be discussed in the next chapter.

Based on the results from Table 4.7 to Table 4.10, there is clear evidence that the effects of amplitude wave modulation are closely related to temperature field changes. The relationship between R-value and temperature indicates that wave amplitude modulation is strongly influenced by heat and electrostatic mechanisms. However, further investigation is needed to identify the contribution mechanism to the wave modulation effect. This relationship shows a clear connection between vibration and acoustic modulation and heat field. Since the plates are always excited, the cracks will not grow but the parameters change the only temperature. Therefore, the value of R is observed with temperature rise shown in Fig. 4.18 to Figure 4.23.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0 Introduction

Base on the results obtained in Chapter 4, a discussion of the finding is presented in this chapter. The findings from the study are used to discuss whether the proposed hypotheses are supported. All research questions will be answered subsequently and finally, the achievement of research objectives are determined. This project is provided with managerial implications and recommendations, to enable them to draft appropriate strategic in gaining to avoid the data taken is wrong based on low-frequency excitation and the effect of excitation positions. Finally, the contributions of the study are discussed based on methodological, practical approaches and end with suggestions for future research.

5.1 Conclusion

Through this project, non-linear acoustics have been studied by seeking information from previous research. From previous studies, non-linear acoustic effects have been used to detect damage to solid materials. There are many methods that use non-linear acoustic effects to detect damage such as cracking on the solid matter. They are acoustic vibration modulation (VAM), impact modulation (IM), non-linear resonance ultrasound spectra (NRUS) and non-linear wave modulation spectrum (NWMS). This method uses the same non-linear acoustic effect to diagnose material defects but each method has a different approach for the preparation of experiments, and the introduction of low-frequency vibrations, and high-frequency ultrasound waves. A non-linear acoustic effect is the transition of resonant frequency, harmonic generation and sideband generation. Mechanisms involving this impression is open/close from cracks, nonlinear elasticity, and material stiffness. This project will use a sideband generation to analyze the relationship between heat dissipation in solid structure and intensity of non-linear acoustic modulation, R-value. As a result, thermal dissipation has been influenced by the intensity of the nonlinear acoustic modulation. This is because the sideband has appeared when high and low frequencies are excited to the plates. In addition, the calculated R-value is directly proportional to the increase in temperature. When low-frequency capital excitation coincides with the crack, there is a clear connection between the temperature field and the intensity of acoustic vibration modulation. Increased temperatures are observed — due to sensitivity to cracking rules — leading to increasing modulation parameter values for the same excitation level used. Although, temperature changes are also observed due to cracking because of friction between crack surfaces.

5.2 Recommendations

Based on the project that has been carried out, the results are different from the expected results. Some problems that may affect the experimental results have been identified where it is introducing low-frequency excitation, excitation position and introducing heat.

5.2.1 Low frequency excitation

In this experiment, electromagnetic shielding is used to stimulate the mod vibration at low-frequency vibration (LF) which is the first vibration mode (66 Hz). Lower edge angle test is placed on the electromagnetic clamp as shown in Figure 5.1 and Figure 5.2. There will be a border effect in the measurement system. The bottom end of the plate has been fixed, and the other end is free. Therefore, the spread of low-frequency signal through the plate is not smooth and uniform. It will affect the system measurements.

Figure 5.1: The position of aluminium plate on electromagnetic shaker.

In addition, the interaction between the shocks attached to the aluminium plate may result in additional non-linear acoustic effects and increased strong noise in the frequency spectrum. The effect of the problem, it will cause sideband effects resulting from the defect specimen, as reported by M. Morbidini et al. [25]. In ensuring the problem is solved, tack actuator can be used to stimulate the vibration at low-frequency vibration (LF) which is vibration mode 1 (66 Hz). It is a fixed drive (5 mm x 5 mm x 2 mm) and can be mounted on a plate using adhesive glue or drill the plate and tie it with a bolt. So, from the solution it can reduce the boundary effect in the measurement system. The aluminium plate can vibrate freely and the signal wave generated from it will propagate through the plate smoothly.

5.2.2 The effects of excitation position

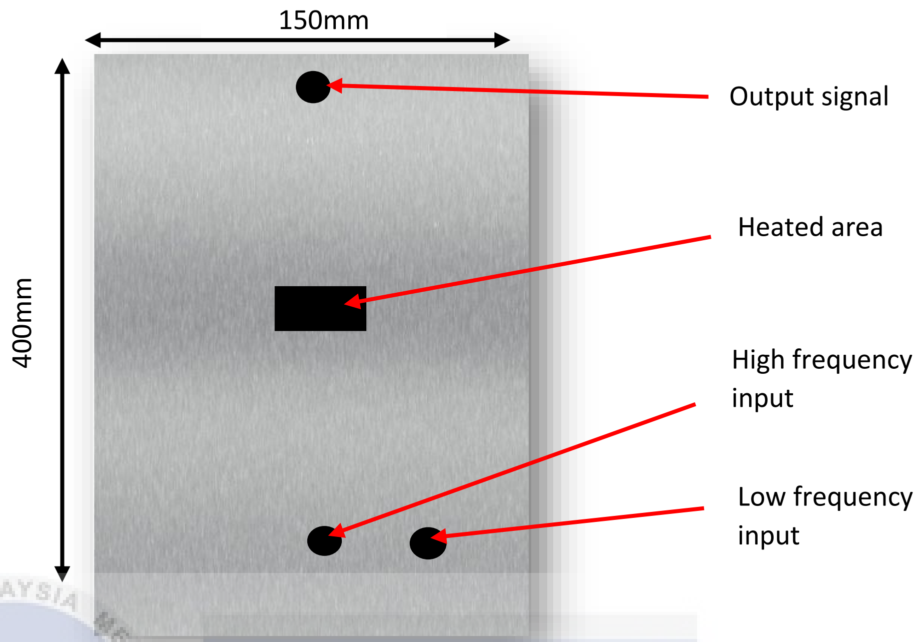

Figure 5.2: Schematic drawing of the aluminium plate along layout of heated area and excitation position (Before changing)

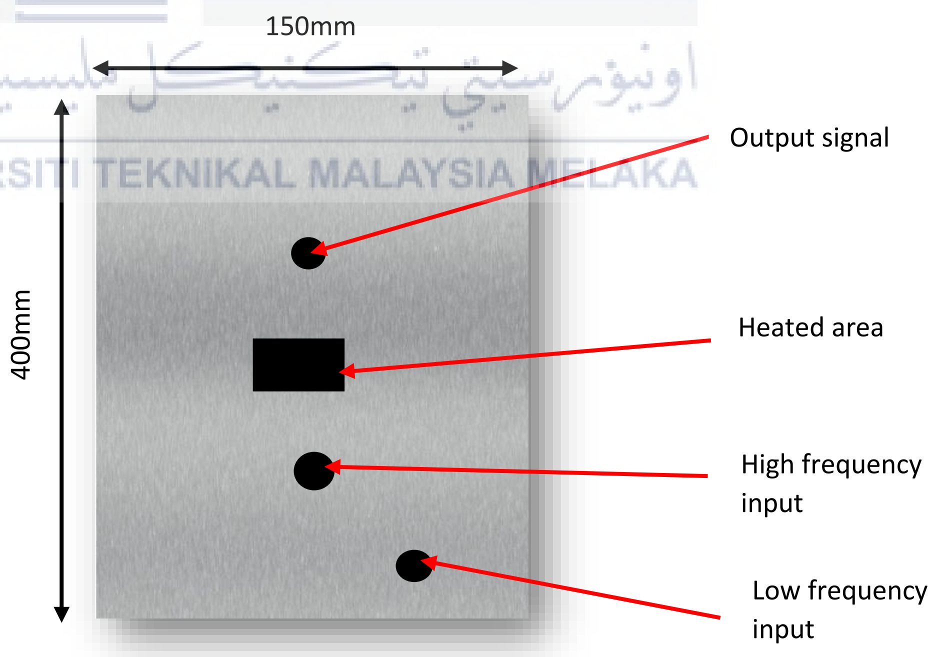

Figure 5.3: Schematic drawing of the aluminium plate along layout of heated area and excitation position (After changing)

When the plate vibrates with a constant harmonic frequency, the plate reacts according to the shape vibration shape, where some parts of the plate will have a nearly zero transitions. This part is known as a node area. To obtain a good harmonic excitation response, the excitation position should be to what extent from any node area. This area should be avoided when low-frequency excitation is used in the vibro-acoustic method.

Referring to figure 5.3, the distance between the inputs of the high frequency and the output of the reaction is far. Signal waves are needed more times to spread through the plates. Therefore, much energy is lost during its use. From the experiment setup, it will affect the output of the signal reaction. Therefore, the results of the experiment are incorrect and will affect the measurement of the system. Therefore, to solve that problem, the distance of the input frequency excitation between the responses of the output must be reduced as shown in Figure 5.4. So, it can reduce the lost energy during wave propagation.

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APPENDIX

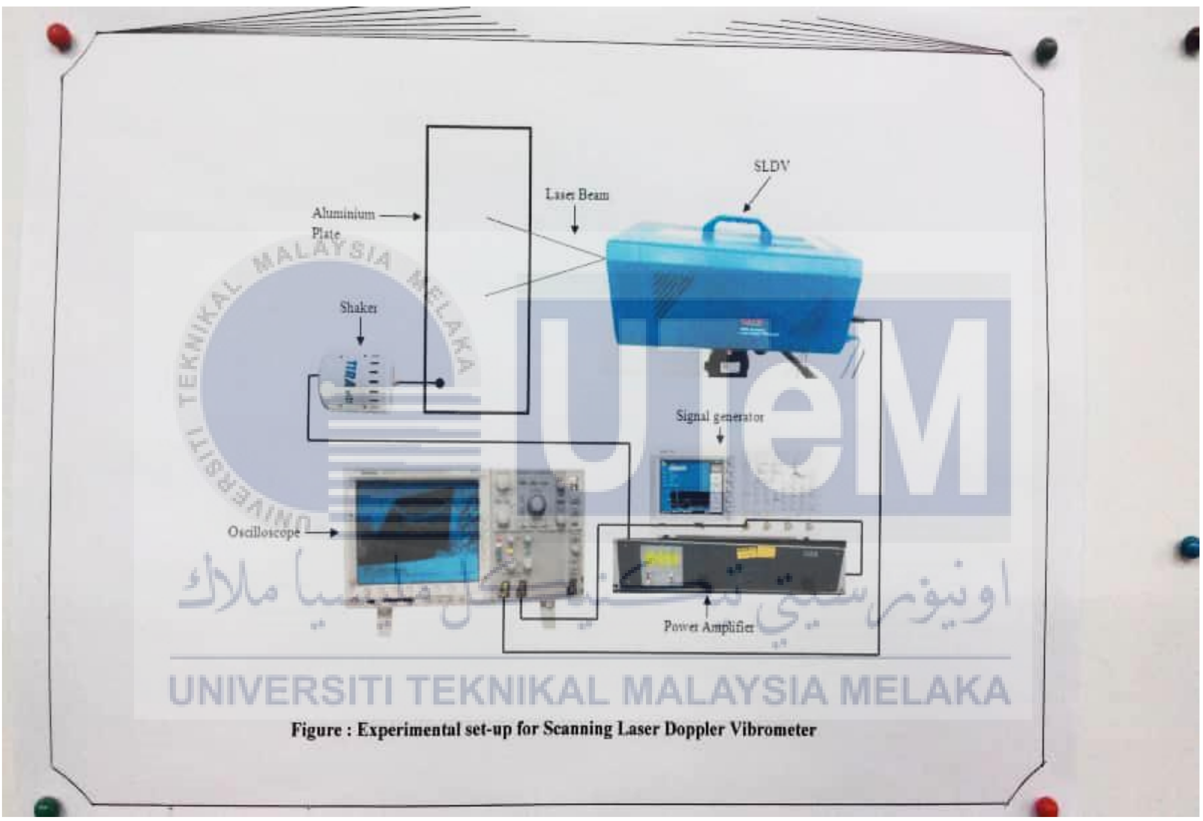

Figure A

No.	Action Plan description	Deadline	Project Execution Period																Remarks/ Comment
			FYP 1 2018																
			WE-EK	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14	W 15	
1.	Collecting literature review which related to the project																		
2	Do the research about experiment method of the project																		
3	Design the experiment base on the method that was research																		
4	Start the experiment by following the procedure and get the result experiment.																		
5	Tabulate the data and use MATLAB to calculate the analysis																		
6	Making full report FYP 1 writing																		
7	Submitting final report of the project																		

Figure B: Gant Chart of the FYP 1

No.	Action Plan description	Deadline	Project Execution Period																Remarks/ Comment
			FYP 2 2019																
			WE-EK	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14	W 15	
1.	Start the experiment by following the procedure and get the result experiment.																		
2	Tabulate the data and use MATLAB to calculate the analysis																		
3	Send progress report FYP 2																		
4	Making full report FYP 2 writing																		
5	Seminar 2																		
6	Submitting draft final report of the project																		

Figure C: Gant Chart of the FYP 2.

FYP ACTIVITIES

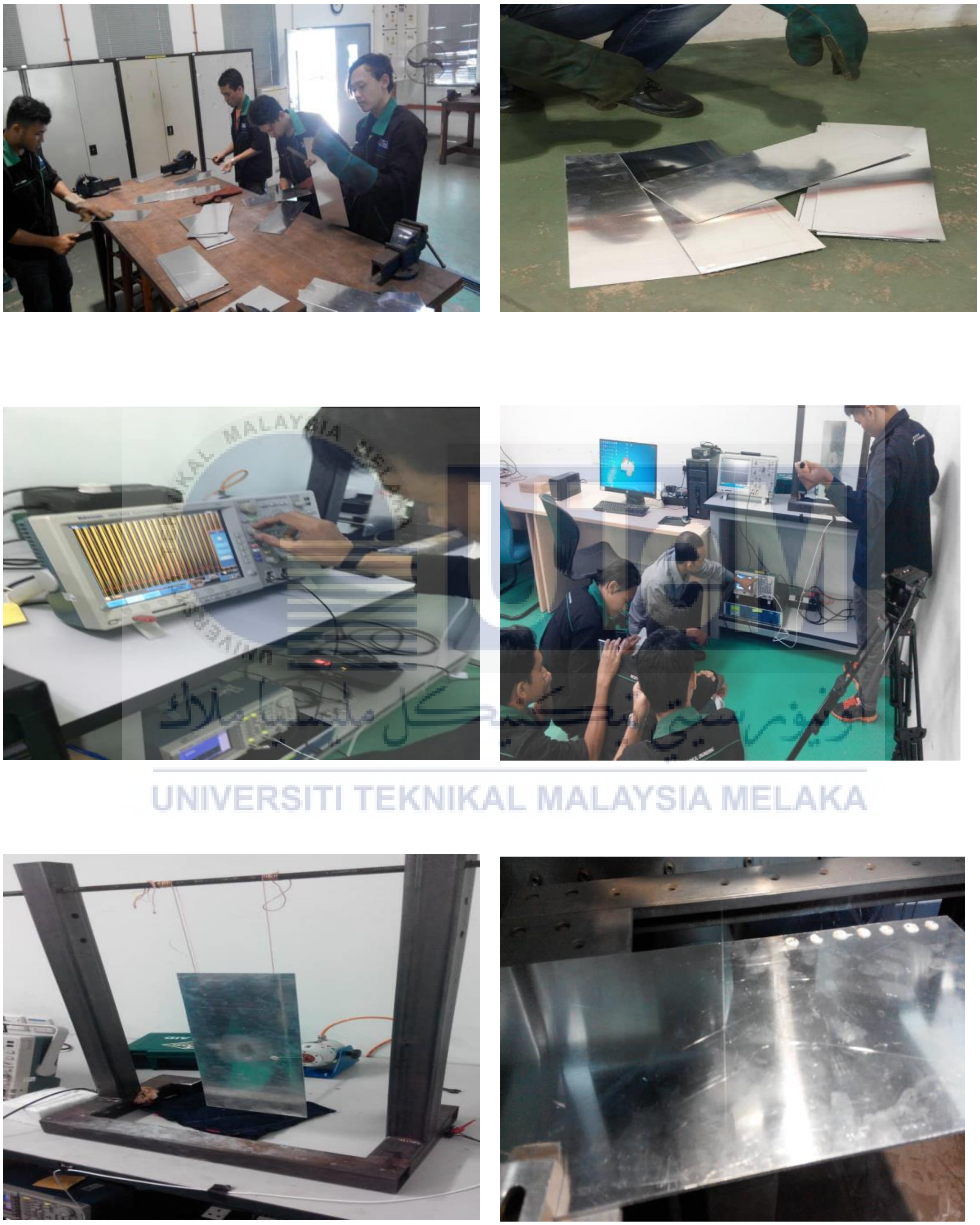

Figure D

MATHLAB Code

```
clear all;
data1 = csvread('tek00010.csv');
f1 = data1(:,1);
amp1 = data1(:,2);
plot(f1,amp1)
title('Single-Sided Amplitude Spectrum of X(t)')
xlabel('f (Hz)')
ylabel('Amp')
xlim([56000 64000])
```

or


```
clear all;
data = csvread('tek00003.csv') ;
t = data(:,1) ;
amp = data(:,2) ;
L = length(t) ;
N = length(amp);
dt = max(diff(t)) ;
Fs = 1/dt ;
%% Single-Sided Amplitude Spectrum of X(t)
Y = fft(amp);
```

```
P2 = abs(Y/L);

P1 = P2(1:L/2+1);

P1(2:end-1) = 2*P1(2:end-1);

f = Fs*(0:(L/2))/L;

semilogy(f,P1)

title('Single-Sided Amplitude Spectrum of X(t)')

xlabel('f (Hz)')

ylabel('Amplitude')

xlim([0 600])

%ylim([ 20])
```