A STUDY OF DYNAMIC CHARATERISTICS FOR CRACK IDENTIFICATION

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JUDUL: **A STUDY OF DYNAMIC CHARATERISTICS FOR CRACK IDENTIFICATION**

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In the name of ALLAH whose guidance, help and grace was instrumental in making this humble work reality. Specially dedicated to my beloved family and those who have Encourage and always be with me during hard times And inspired me throughout my journey of learning. Also to my supervisor, Mr Mohamad Zairi and co-supervisor, Mr.Che Ku Eddy for their guide and help especially in finishing this project report.

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ABSTRACT

Experimental modal analysis has become a commonly-used technique for studying the dynamical behaviour of mechanical and civil structures. During a modal test, both the applied forces and vibration responses of the structure are measured when excited in one or more locations. Based on this data, a modal model of the structure, that essentially contains the same information as the original vibration data, is derived by means of system identification. The objective of this project is to detect crack using dynamic characteristics. Four set of specimen were tested with three of them have a different depth of crack which is 10%, 20% and 50%. The healthy specimen was used as baseline data to compare with the crack specimen. The aim of this thesis was to use the modal testing methods as a starting point to develop more advanced modal parameter identification techniques. The data was collected using Dasylab software with a specified block diagram. First, the data of the beam will be used to simulate in the Algor software in order to determine the natural frequency and mode shape of the beam. Experiment was done and the data will analysed by using ME Scope software. From the result, mode shape and natural frequency plays an important role in supporting result analysed by using Algor that will be used on Me Scope software. The data of simulation results will be guidelines for interpret data from experiment of modal testing. Five modes were determined and the value of natural frequency in each mode was increased respectively. If the value of natural frequency shifted means that the specimen was having crack on it. If the shifted is too much means that the specimen having a deeper crack. Then mode shape was used in order to validate whether the specimen is having crack or not. Mode shape 5 was too significant which is first bending mode in y direction compared to the other mode. If the mode shape is a 1st bending mode in y direction, and also natural frequency was shifted, then it shows that the specimen is having a crack on it.Finally, the modal testing method proves to be an effective method for crack identification.

ABSTRAK

Eksperimen modal analisis telah menjadi satu teknik yang biasa digunakan untuk mengkaji kelakuan dinamik struktur mekanikal dan sivil. Semasa ujian modal, kedua-dua daya yang dikenakan dan maklum balas getaran struktur diukur apabila teruja dalam satu atau lebih lokasi. Berdasarkan data ini, satu model mod struktur, yang pada asasnya mengandungi maklumat yang sama seperti data getaran asal, yang diperolehi melalui pengenalan sistem. Objektif projek ini adalah untuk mengesan retak menggunakan ciri-ciri dinamik. Empat set spesimen diuji dengan tiga daripada mereka mempunyai kedalaman yang berbeza retak iaitu 10%, 20% dan 50%. Spesimen yang sihat telah digunakan sebagai data asas untuk membandingkan dengan spesimen retak. Tujuan projek ini adalah untuk menggunakan kaedah ujian modal sebagai titik permulaan untuk membangunkan modal teknik pengenalan parameter yang lebih maju. Data telah dikumpulkan menggunakan perisian Dasylab dengan gambarajah blok yang ditetapkan. Pertama, data rasuk akan digunakan untuk meniru dalam perisian Algor dalam usaha untuk menentukan frekuensi asli dan bentuk mod rasuk. Percubaan telah dilakukan dan data akan dianalisis dengan menggunakan perisian ME SCOPE. Dari hasil, bentuk mod dan frekuensi semulajadi memainkan peranan penting dalam menyokong hasil dianalisis dengan menggunakan Algor yang akan digunakan pada Me perisian Skop. Data keputusan simulasi akan garis panduan bagi mentafsir data daripada eksperimen ujian mod. Lima mod ditentukan dan nilai frekuensi semulajadi dalam setiap mod telah meningkat masing-masing. Jika nilai frekuensi semulajadi beralih bermakna bahawa spesimen itu mempunyai retak di atasnya. Jika beralih terlalu banyak cara bahawa spesimen yang mempunyai retak yang lebih mendalam. Kemudian bentuk mod telah digunakan untuk mengesahkan sama ada spesimen itu mempunyai retak atau tidak. Bentuk mod 5 adalah terlalu besar yang pertama mod lentur dalam arah y berbanding dengan mod lain. Jika bentuk mod ialah cara 1 lentur dalam arah y, dan juga frekuensi semulajadi telah dipindahkan, maka ia menunjukkan bahawa spesimen itu mempunyai keretakan it.Akhir sekali, kaedah ujian modal terbukti menjadi satu kaedah yang berkesan untuk mengenal pasti retak.

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LIST OF SYMBOLS

P1	Axial Force
P2	Bending moment
al	Transverse surface crack of depth
B	Beam of width
W	Height

LIST OF ABBREVIATIONS

3D	Three Dimensional view
FFT	Fast Fourier Transform
DASYLab	Data Acquisition System Laboratory

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

This chapter discusses the about the project background, problem statement, the objectives, scopes of project, project flow and project Gantt chart. Besides that, it also consists with the thesis overview for this project.

1.1 PROJECT BACKGROUND

Nowadays, all the structures, buildings, vehicles and other things that related in engineering is important to considered as a good and safe. The key word which is safety is totally important in order to raise the rank and also standards of engineering, same goes to the technology and achievement reached by engineering.

Basically the ability to monitor and to predict some kind of damage of the structure at the earlier stage is totally gain interests to the all engineer as the material recently mostly come in low quality. In order to achieve that, many ideas and method had been thought like a variety of investigations have been carried out on structures with an overview of hypothesis. Recently, vibration investigation of damaged structure has become an approach for fault diagnosis with a view to developing robust crack detection procedures (Lang et al, 2007). Any crack or localized damage, no matter the damage or crack is small, tiny, large in any structure can introduces a local flexibility which absolutely can change the dynamic behavior of any structures experiencing the damage or crack on it (Peng et al, 2006). Besides, it also can cause the stiffness reduced and for sure, the damping on the structure increase dramatically.

As for now, many methods or procedure for detection of crack or damage on any structure has been discussed and investigated by many persons. There are several factors that can be considered to determine whether the structures are experiencing damage or crack like natural frequency, mode shapes, phase and so on (Bilings et al, 2007).

Reduction in stiffness is associated with decreases in the natural frequencies and also modifications of mode shape of the structure which means that stiffness is important to be considered also in order to estimate the location and depth of crack or any damage on the structures. An analysis on reduction of natural frequencies and change of the mode shapes of vibration makes it possible to identify cracks or damage on any structures. Based on statistics, there are some reasons why the natural frequencies and mode shapes of the structure are always be factors to be considered while detecting the crack and damage. Since it can determine only the small cracks and tiny damage, more sensitive or precise methods are been held based on researches and some kind of investigations. Therefore, not only small cracks and tiny damage can be detect but large cracks and rough damage on any structures in earlier stages before anything bad happens in real worlds.

It is required that structures must safely work during its service life but damages initiate a breakdown period on the structures. Cracks are among the most encountered damage types in the structures. Cracks in a structure may be hazardous due to static or dynamic loadings, so that crack detection plays an important role for structural health monitoring applications. Beam type structures are being commonly used in steel construction and machinery industries.

In the literature, several studies deal with the structural safety of beams, especially, crack detection by structural health monitoring. Studies based on structural health monitoring for crack detection deal with change in natural frequencies and mode shapes of the beam. The most common structural defect is the existence of a crack. Cracks are present in structures due to various reasons (Chati et al, 1997).

The presence of a crack could not only cause a local variation in the stiffness but it could affect the mechanical behavior of the entire structure to a considerable extent. Cracks may be caused by fatigue under service conditions as a result of the limited fatigue strength. They may also occur due to mechanical defects. Another group of cracks are initiated during the manufacturing processes. Generally they are small in sizes. Small cracks are known to propagate due to fluctuating stress conditions. If these propagating cracks remain undetected and reach their critical size, then a sudden structural failure may occur.

Hence it is possible to use natural frequency measurements to detect cracks. In the present investigation a number of literatures published so far have been surveyed, reviewed and analyzed. Most of researchers studied the effect of single crack on the dynamics of structures. However in actual practice structural members such as beams are highly susceptible to transverse cross-sectional cracks due to fatigue.

Therefore an attempt has been made to investigate the dynamic behavior of basic structures with crack systematically. The objective is to carry out vibration analysis on a cantilever beam with and without crack. The results obtained analytically are validated with the simulation results. In first phase of the work two transverse surface cracks are included in developing the analytical expressions in dynamic characteristics of structures.

These cracks introduce new boundary conditions for the structures at the crack locations. These boundary conditions are derived from strain energy equation using castiligiano's theorem (Mukherjee et al, 1997). Presence of crack also reduces stiffness of the structures which has been derived from stiffness matrix. The detailed analyses of crack modeling and stiffness matrices are presented in subsequent sections.

Euler-Bernoulli beam theory is used for dynamic characteristics of beams with transverse cracks. Modified boundary conditions due to presence of crack have been used to find out the theoretical expressions for natural frequencies and mode shape for the beams.

1.2 PROBLEM STATEMENT

Base on the title given which is a study on dynamic characteristics for crack identification, there have a few problem statement existed.

i. In automotive sector, most parts like lower arm, crankshaft experiencing crack on it.
ii. Early detection of crack on the automotive part is important to predict the failure on it.
iii. To avoid rupture of the automotive parts before and after using it.

1.3 OBJECTIVES

According to the project background and problem, the objectives of the project are:

i. To conduct a modal testing for crack identification on cantilever beam.
ii. To determine dynamic characteristics of the modal testing applied on the beam
iii. To analyse natural frequency and mode shape of the beam.

1.4 PROJECT SCOPES

In order to reach the project's objectives, the following scopes are identified:

i. The beam will vary in depth which is 0%, 10%, 20% and 50%.
ii. To know the dynamic properties like mode shape and natural frequency.
iii. Material that is going to be used in this modal testing is mild steel.

1.5 EXPECTED OUTCOMES

From this project, the expected outcomes are:

i. Present and proposed the experimental results.
ii. Compare the experimental results with simulation results of the mild steel beam.

iii. Produce the best way to detect a crack on any structures based on the dynamic characteristics.

1.6 PROJECT FLOW CHART

In conducting a project, well arrangement of works and task is important to keep the momentum of this study. Figure 1.1 shows the flow chart for this project. The process started with identify the problem statement especially problem face in industry, the objectives and scopes of this project. After that, the problem identification will follow the flow and continue with the finding the related journal or literature review about this title. It will help to gain the knowledge and also help to discuss about this project.

The next step will be continued in Final Year Project 2 (FYP2) which is the data will be analysed by using ME SCOPE software. At this step, the data from DASY lab will generate in ME SCOPE software. After the result of the analysis had validation to detect the crack identification compare to the simulation result, then the data will be saved.

Figure 1.2 shows Gantt chart for FYP 1 are shows the overall activities for final year project one. Start with briefing from supervisor and co-supervisor, discuss about the related topic. Current progresses are behind schedule within one week because need more understanding the theory. Next activities are learning software. Install DASYLab software at week three and learn basic theory of DASYLab such as sampling, blog size, and others module function to support experiment and next is finding journal that related to the topic. Both activities are also behind the schedule as plan because my supervisor had suggestion a certain technique to improve for my blog diagram experiment.

There are misunderstandings about of this topic, for this topic does not have to do modal testing, thus co-supervisor ask focus on vibration response on shaft component. For specimen material, need to check the grade of low carbon steel by using spectrometer at casting laboratory. The rest of activities are following schedule, except check draft report with supervisor, which has earlier a week. Figure 1.2 also shows Gantt chart for FYP 2, more on fabricate the specimens for experiment testing, run experiment. Discuss the data from experiment with supervisor. Then, do the draft report and prepare for presentation.

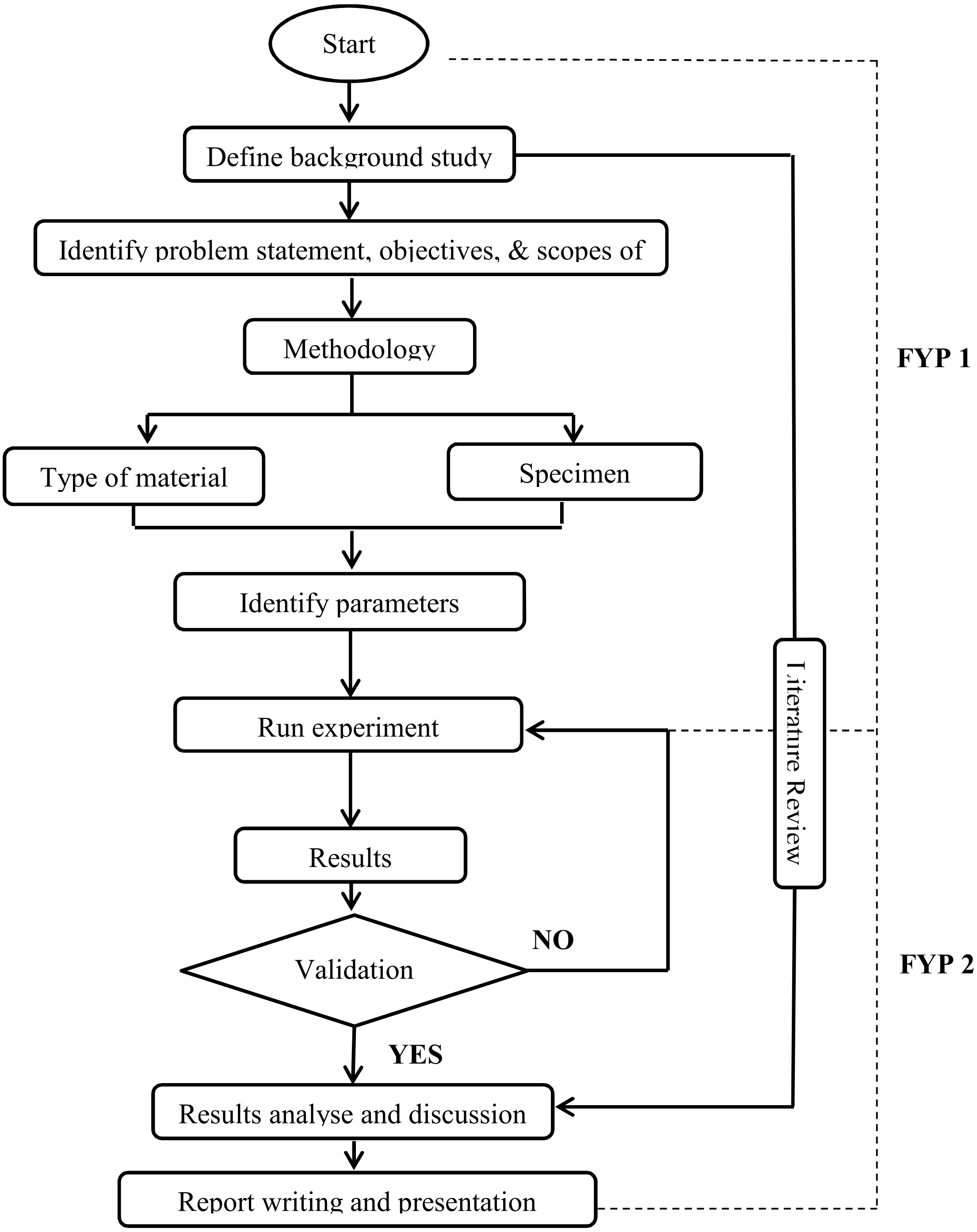

Figure 1.1: Project's Flow Chart

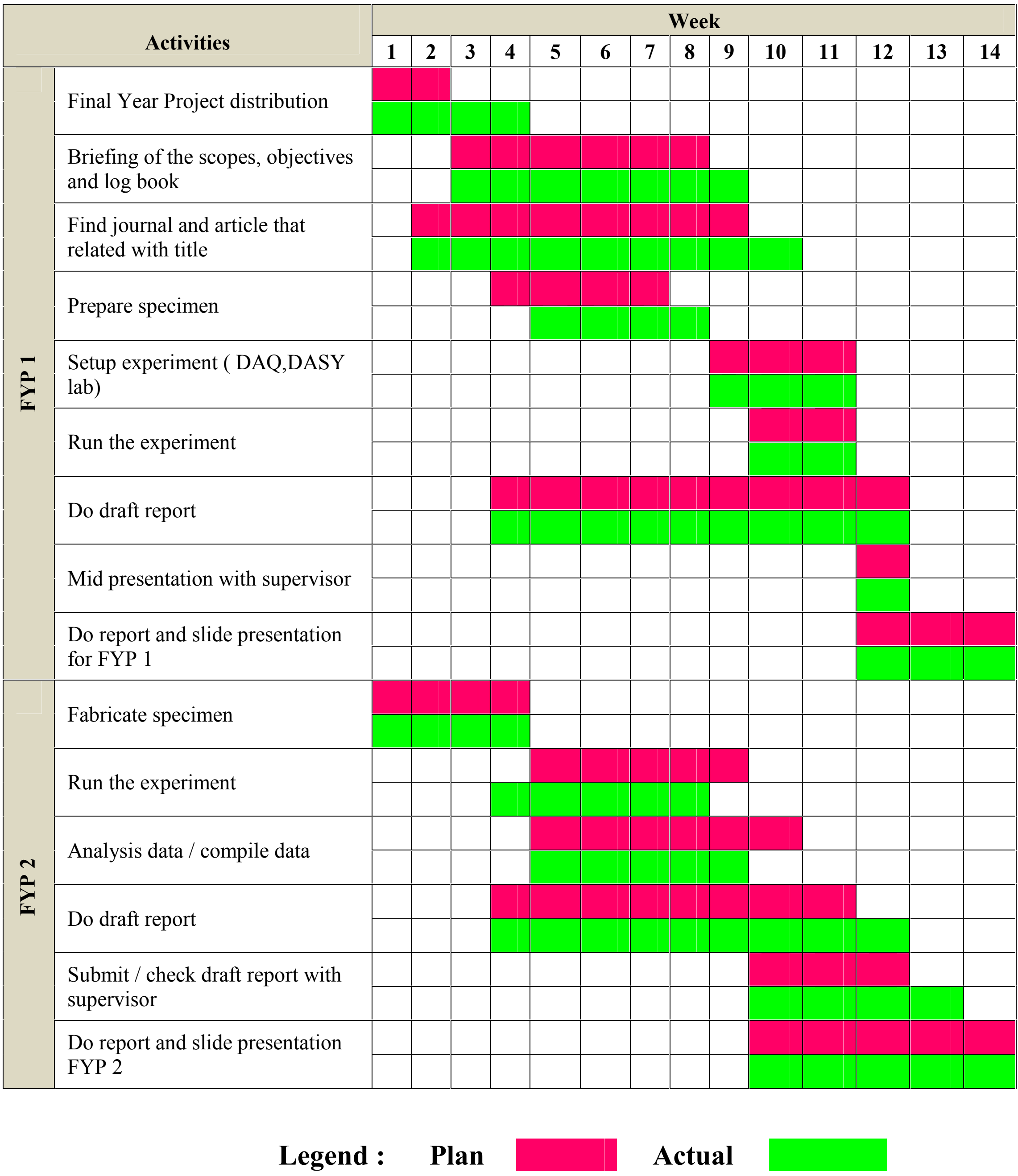

Figure1.2: Gantt chart FYP 1 & FYP 2

1.7 THESIS OVERVIEW

Chapter 1 introduces the background of the study. It is continue with simple discussion about what is about study of dynamic characteristics for crack identification, several ways or procedures to determine it, some others factors should be considered, problems statement which related to the study, the objectives, scope of the study, the expected outcomes and the structure of the thesis.

Chapter 2 information of natural frequency and phase for crack identification, design consideration of beam in Algor software, type of beams that will be used, comparison between type of crack depth ratio and healthy beam, material selection, , types of testing applied and software to be implemented**.**

Chapter 3 includes the all proposed design where the physical parameter, consideration, and defect will be considered. This chapter also will discuss about construction and build up of experimental of the modal testing applied to the mild steel beam, the design or flow process that go through the beam before experiencing modal testing, and technical specification of the entire suggested model

Chapter 4 will present the result obtained and discussion about the modal testing applied on the cantilever beam for crack identification. Analysis also will be done for the results by comparing the natural frequency and mode shape of the four specimens

This study will enclosed by chapter 5 with the conclusion for this project and recommendation for future research.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

This chapter discussed on literature review of crack identification, modal testing and also a simulation analysis.. The chapter starts with the introduction of modal testing and process through it, and then the design consideration of the beam can be used will be discussed to guide through this project. Furthermore, this chapter also covers about type of experimental and analysis, comparison between parameters, material selection of the cantilever beam, types and sum of process experienced, and the use of several software that related for this project.

2.1 OVERVIEW

Cracks are a potential source of catastrophic failure in mechanical machines, in civil structures and aerospace engineering. In order to avoid failure caused by cracks, many researchers have performed extensive investigations over the years to develop structural integrity monitoring techniques.

Most of the techniques are based on vibration measurement and analysis .In most cases, vibration based methods can offer an effective and convenient way to detect fatigue cracks in structures. It is always require that structure must safely work during its service life, however damage initiates a breakdown period on the structures. It is unanimous that cracks are among the most encountered damage types in structures. Crack in structures may be hazardous due their dynamic loadings. Therefore, crack detection plays an important for structural health monitoring applications.

Many researchers have used the free and forced vibration techniques for developing procedures for crack detection. The eventual goal of this research is to establish new methodologies which will predict the crack location and crack depth in a dynamically vibrating structure with the help of intelligence technique with considerably less computational time and high precision. This chapter recapitulates the previous works, mostly in computational methods for structures, and discusses the possible ways for research.

2.2 MODAL ANALYSIS

Modal analysis refers to the process of estimating the modal properties like the resonance (or modal) frequencies, modal damping and mode shapes, of a system. A common example of resonance behavior is the opera singer who apocryphally strikes a sustained high note which causes a nearby wine glass to shatter. In fact, all physical systems exhibit resonance frequencies, and the consequences of exciting these frequencies can be equally dire for an aircraft in flight as for the opera singer's glass.

More generally, the dynamic behavior of a system such as an aircraft can be predicted with knowledge of its modal properties. Indeed, the response of a linear system to excitation can be expressed as a sum of the contributions from all the modes of the system. To make such a prediction, analysts use a mathematical model known as a modal model.

2.2.1 Modal testing

Modal testing is one of famous method in vibration. Modal testing can be achieved by introducing a forcing function into a certain structure. Usually with some type of shaker and familiar ways that are usually be used is like an impact testing some shaker that used in the lab. Experimental modal testing is used to describe the dynamic behaviour of structures (Kenneth, 2012). In other words, a structure that want to be tested is attached to shaker, like a surface containing a few spring that can be shake during handling an experiment.

The beam clamped in a table is to induce distinctive modal bending frequencies between bending planes (Jacques et al, 2000). Instantly, for a relatively low frequency forcing, an electronic devices called as a servo hydraulic are used and for higher frequency an electrodynamics shakers are used. In my project, excitation forces is prefer to come from an impact hammer as it is not complicated and easily can be used. For this crack identification which used a modal testing as an experiment, the preferred way to give force to the beam is using the impact hammer.

When we use this impact hammer, it gives a perfect impulse which has an infinitely small duration causing constant amplitude in the frequency domain, resulting in all modes of vibration being excited with equal energy. In order to minimize torsional vibration an impact hammer will generates an excitation centred on the neutral axis of the beam (Yvon et al, 2000).

2.3 SIGNAL ANALYSIS

Signal analysis is an area of systems engineering and applied mathematics that deals with operations on or in other words we call it as signal processing. Signal analysis can be including sound, images and sensor of data like control systems signal, transmissions signals and many others.

There are several categories in signal analysis which is signal acquisition, quality improvement and also feature extraction. Based on the research done and journal, suitable categories will be signal acquisition as it involves measuring a physical signal, storing it and possibly later rebuilding the original signal. In this experiment signal analysis can be get by the Dasylab software and also Algor software. Signal processing such as spectrograms has been improve since it has enough accuracy to display the behaviour of an uncracked beam (Serge Lalonde et al, 2000).

Many people proposed linear techniques like FRF (Frequency Response Function) to detect cracks. These techniques are limited by drifts in measurement conditions and structural loading conditions (Francois et al, 2000). A frequency response function is a transfer function which expressed in the frequency domain.

Frequency response function is complex functions with real and imaginary components. They also may be represented in terms of magnitude and phase (Tom Irvine, 2000).

2.3.1 Natural frequencies and excitation frequencies

If a structure is subjected to frequencies which coincide with any of its natural frequencies, resonance will occur and the structure will be unstable. The consequence of this is often large oscillation and an eventual high cycle fatigue failure. For rotating applications such as compressors and turbines, it is necessary to be well aware of the natural frequencies in all included components. By the design of a component, it is possible to control the natural frequencies and to keep them separated from the frequencies of applied load, the excitation frequencies. The method used to determine natural frequencies of a structure is called modal analysis.

Excitation frequencies generally considered in a rotating structure are so called engine order frequencies which arise from the speed of rotation. If the rotational velocity, ω, is measured in rpm and the excitation frequency, f, in Hz, the first engine order is defined according as in equation 2.1:

$$\frac{1}{60} = \frac{f}{T} = \omega \tag{2.1}$$

The other engine orders are multiples of this frequency and correspond to the number of disturbances per revolution. Thus, engine order two corresponds to the frequency obtained when the structure receives two disturbances per revolution and is calculated by multiplying equation 2.1 by factor 2. This linear relation between rotational velocity and excitation frequency is later included in a Campbell diagram.

2.3.2 Mode shape

If an application is tuned in one of its natural frequencies it will start to vibrate in a certain pattern of movement, called modal shape. A common example used to describe modal shapes is a vibrating, circular disk. If a natural frequency of the disk coincides with an excitation frequency, the disk will start to oscillate.

For such oscillations is it possible to observe a number of lines on the application with zero axial displacement. These lines are called nodal diameters or nodal circles depending on their appearance. The number of nodal diameters and nodal circles is used to name the current modal shape according to Figure 2.1. The different colours in the figure symbolize positive and negative oscillating amplitude. Nodal diameter zero is often called an umbrella mode due to its pattern of motion. Modes are further characterized as either rigid body or flexible body modes. All structures can have up to six rigid body modes, three translational modes and three rotational modes. If the structure merely bounces on some soft springs, its motion approximates a rigid body mode.

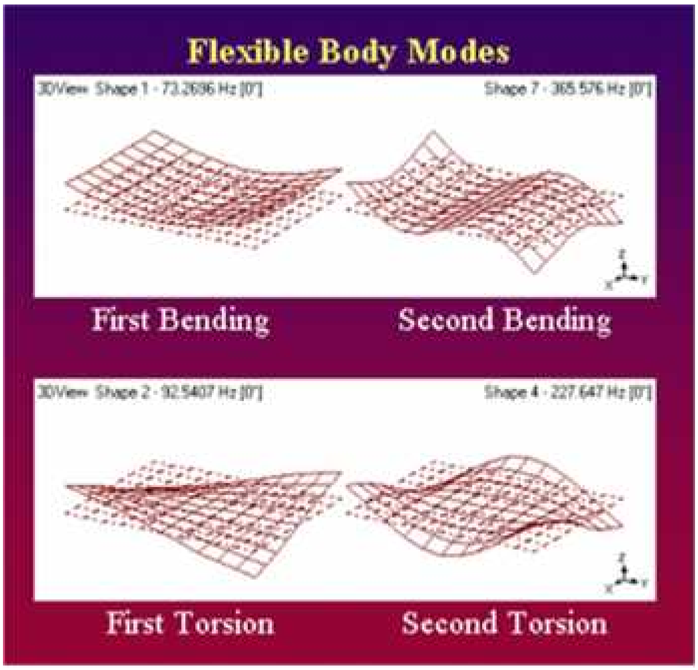

Figure 2.1: Flexible Body Modes

Source: Brian et al, Experimental Modal Analysis 1999

Many vibration problems are caused, or at least amplified by the excitation of one or more flexible body modes. Figure 2 shows some of the common fundamental (low frequency) modes of a plate. The fundamental modes are given names like those shown in Figure 2.1 The higher frequency mode shapes are usually more complex in appearance, and therefore don't have common names.

2.3.3 Excitation mechanism

Excitation is any form of input that is used to create a response in a structural system. This can include environmental or operational inputs as well as the controlled force input(s) that are used in Experimental Modal Analysis. The following section is limited to the force inputs that can be controlled. The primary assumption concerning the excitation of a linear structure is that the excitation is observable. Whenever the excitation is measured, this assumption simply implies that the measured characteristic properly describes the actual input characteristics.

If the excitation is not measured, modal scaling parameters (modal mass, modal A, residues, etc.) cannot be estimated. Even when the estimation of modal scaling parameters is not required still an assumption must be made, concerning the characteristics of the excitation of the system. Inputs which can be used to excite a system in order to determine frequency response functions belong to one of the two classifications which are random signals and deterministic signals (Avaitable, 1998). Random signals are defined by their statistical properties over some time period and no mathematical relationship can be formulated to describe the signal whereas deterministic signals can be represented in an explicit mathematical relationship.

Deterministic signals are further divided into periodic and non-periodic classifications. The most common inputs in the periodic deterministic signal designation are sinusoidal while the most common inputs in the non-periodic deterministic designation are transient in form. Mostly periodic input signals are generated by using shaker. Figure 2.2 shows general view of impact testing in experimental modal analysis.

Figure 2.2: General views of impact hammer testing

Source: Advanced Material Research, 2008

Swept sine periodic deterministic signals are used in this study for frequency response function estimation. The swept sine signal is a periodic deterministic signal with a frequency that is an integer multiple of the FFT frequency increment. Sufficient time is allowed in the measurement procedure for any transient response (due to change in frequency) to decay so that the resultant output response is periodic with respect to the sample period. Therefore, the total time needed to compute an entire frequency response function are functions of the number of frequency increments required and time allowed for transient responses to decay.

The following paragraphs summarize the terminology used in swept sine excitation method such as Delay Blocks and Capture Blocks. Delay blocks is the number of continuous blocks of excitation that take place without the associated input and output data being acquired are referred as Delay Blocks. Delay Blocks are needed in order to give the transient response to decay out of the response signal. Transient responses are occurred due to start or change in the periodic excitation. So both input and output responses will be periodic within the observation period (T). This is why swept sine excitation method is time consuming. The length of each delay block is equal to the length of the observation period (T). Number of delay blocks is normally chosen as integer. The delay blocks are not recorded and are not used in FRF estimation. Capture Blocks is the number of capture blocks refers to the number of continuous blocks of time data (input and output) that are recorded (captured). Number of capture blocks is also the number of cyclic averages that will be used to estimate FRF measurement. There are several periodic and non-periodic deterministic signals and also several non-deterministic signals. Since the details of signal type properties are out of the scope this study they are not explained here. Table 2.1 below shows a general list of most commonly used for frequency response function estimation (Allemang, 1998)

Table 2.1: Various Signals used in Frequency Response Estimation

Name	**Signal Type**
Swept Sine	Periodic Deterministic
Periodic Chirp	Periodic Deterministic
Impact (Impulse)	Non periodic(transient) Deterministic
Step Relaxation	Non periodic(transient) Deterministic
Pure Random	Ergodic, stationary random
Pseudo Random	Ergodic, stationary random
Periodic Random	Ergodic, stationary random
Burst Random	Both , transient deterministic and Ergodic stationary random

With the ability to compute FRF measurements in an FFT analyser, impact testing was developed during the late 1970's, and has become the most popular modal testing method used today. Impact testing is a fast, convenient, and low cost way of finding the modes of machines and structures as shown below on Figure 2.3.

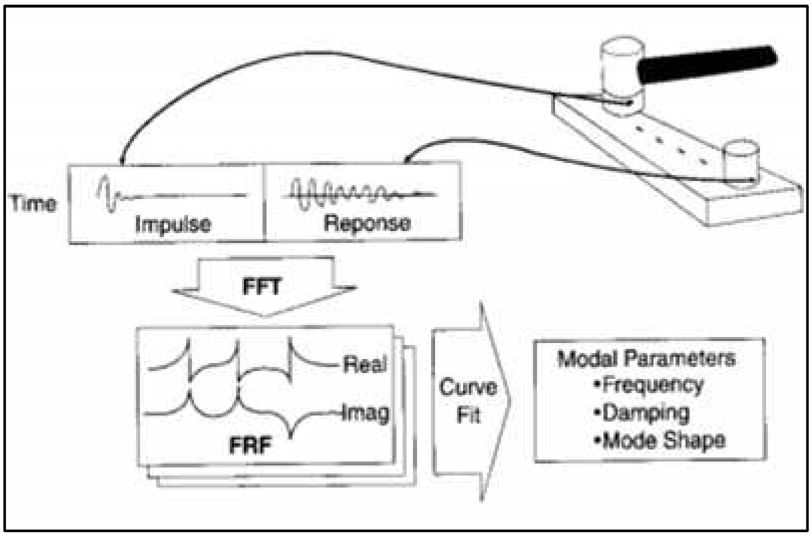

Figure 2.3: Impact Hammer Testing

Source: Richardson et al, Identification of the Modal properties, 1974

Impact testing is depicted in Figure 2.3. The following equipment is required to perform an impact test,

i. An impact hammer with a load cell attached to its head to measure the input force.
ii. An accelerometer to measure the response acceleration at a fixed point & direction.
iii. A 2 or 4 channel FFT analyser to compute FRFs.
iv. Post-processing modal software for identifying modal parameters and displaying the mode shapes in animation.

A wide variety of structures and machines can be impact tested. Of course, different sized hammers are required to provide the appropriate impact force, depending on the size of the structure; small hammers for small structures, large hammers for large structures. Realistic signals from a typical impact test are shown in Figure 2.4 and Figure 2.5.

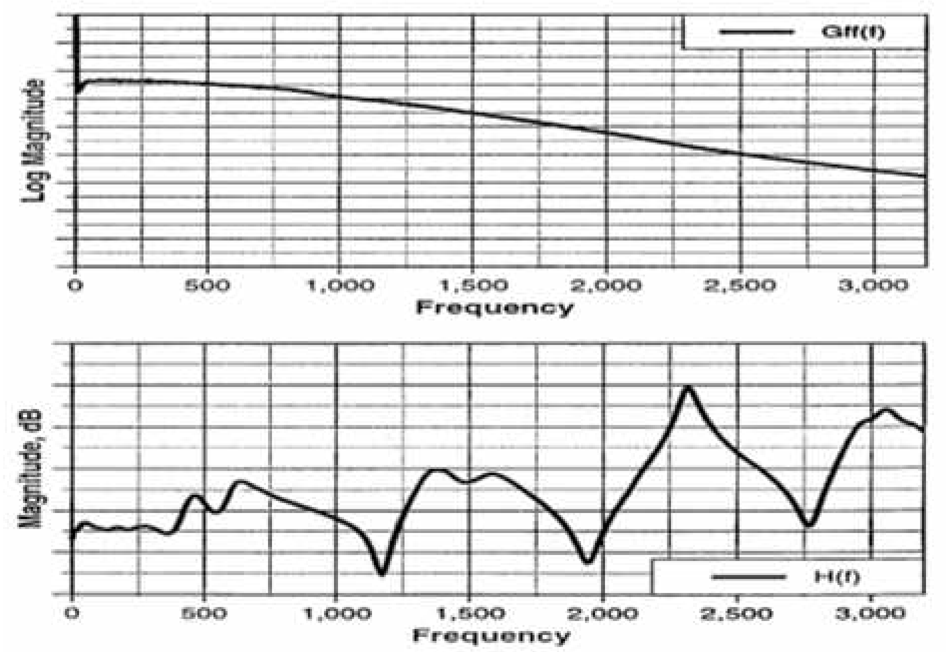

Figure 2.4: Impact Force and Response Signals

Source: G.T Cowley et al,Frequency Response Function,1985

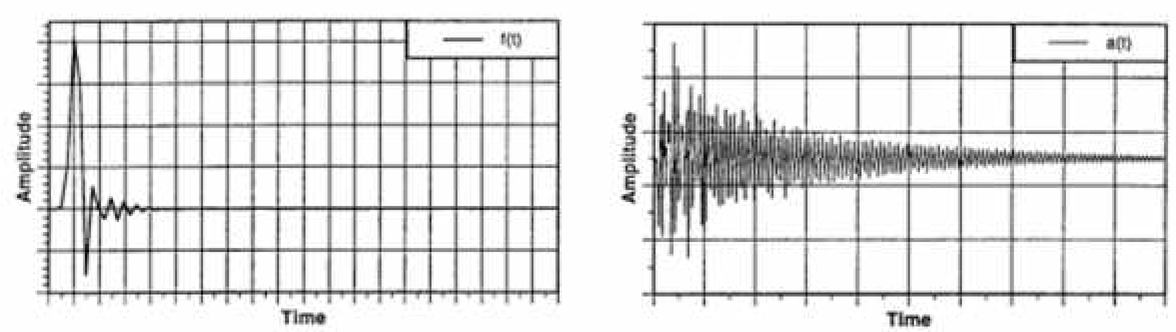

Figure 2.5: Impact APS and FRF

Source: Formenti, Global Curve Fitting of Frequency Response Measurement, 1985

2.3.4 Roving Hammer Test

A roving hammer test is the most common type of impact test. In this test, the accelerometer is fixed at a single DOF, and the structure is impacted at as many DOFs as desired to define the mode shapes of the structure. Using a 2-channel FFT analyser, FRFs are computed one at a time, between each impact DOF and the fixed response DOF (Formenti et al, 1985).

2.3.5 Roving Tri-axial Accelerometer Test

The only drawback to a roving hammer test is that all of the points on most structures cannot be impacted in all three directions, so 3D motion cannot be measured at all points. When 3D motion at each test point is desired in the resulting mode shapes, a roving tri-axial accelerometer is used and the structure is impacted at a fixed DOF with the hammer. Since the tri-axial accelerometer must be simultaneously sampled together with the force data, a 4-channel FFT analyser is required instead of a 2-channel analyser (Formenti et al,1985).

2.3.6 FRF measurement

The Frequency Response Function (FRF) is a fundamental measurement that isolates the inherent dynamic properties of a mechanical structure. Experimental modal parameters (frequency, damping, and mode shape) are also obtained from a set of FRF measurements (Richardson et al, 1975).

The FRF describes the input-output relationship between two points on a structure as a function of frequency, as shown in Figure 3. Since both force and motion are vector quantities, they have directions associated with them. Therefore, an FRF is actually defined between a single input DOF (point & direction), and a single output DOF (Brian et al, 1999).

An FRF is a measure of how much displacement, velocity, or acceleration response a structure has at an output DOF, per unit of excitation force at an input DOF. Figure 2.6 also indicates that an FRF is defined as the ratio of the Fourier transform of an output response (X(w)) divided by the Fourier transform of the input force (F(w)) that caused the output.

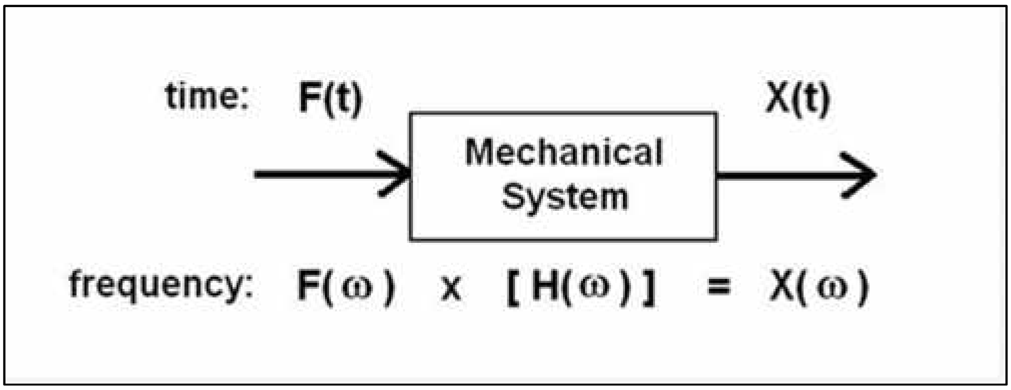

Figure 2.6: Ratio of the Fourier transform

Source: Vold et al, The Numerical Implementation of a Multi-Input Estimation, 1982

Depending on whether the response motion is measured as displacement, velocity, or acceleration, the FRF and its inverse can have a variety of names:

i. **Compliance** = (displacement / force)
ii. **Mobility** = (velocity / force)
iii. **Inertance or Receptance** = (acceleration / force)
iv. **Dynamic Stiffness** = (1 / Compliance)
v. **Impedance** = (1 / Mobility)
vi. **Dynamic Mass** = (1 / Inertance)

An FRF is a complex valued function of frequency that is displayed in various formats, as shown in Figure 2.7

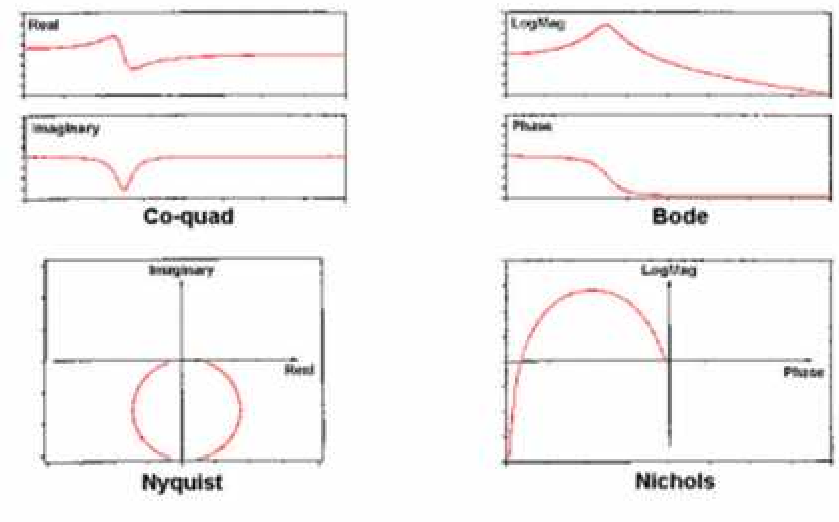

Figure 2.7: Block diagram of an FRF

Source: Richardson et al,Frequency Response Functions,1985

2.4 CANTILEVER BEAM

In a cantilever beam, one end is free and the other one is clamped (Morteza H et al, 2007). The beam carries the load to the support where it is forced against by moment and shear stress. Cantilever construction allows for overhanging structures without external bracing and it also can be constructed with trusses or slabs. This is a totally different as a simple supported beam such as those found in a post and lintel system because a simply supported beam is supported at both ends with loads applied between the supports.

One method for finding and detect crack is from frequency analysis of a cantilever beam. When a vertical load or force is applied it will deform a curve and the beam will return to its original shape but its inertia will keep the beam in motion. So, thus the beam will vibrate at its characteristics frequencies. If a crack is exist on the beam it will altered the flexural rigidity and absolutely this changes will cause the frequency of vibrations to shift (Abdul Jalil et al,2009).A new cantilever beam apparatus has been developed to measure static and vibrational properties of small and thin samples of wood or composite panels.

The apparatus applies a known displacement to a cantilever beam measures its static load then releases it into its natural first mode of transverse vibration. Free vibrational tip displacements as a function of time were recorded. Cantilever beam static modulus and dynamic modulus of elasticity linearly correlated well but were consistently higher than standard mid-point bending modulus of elasticity having linear correlations of 1.12:1 and 1.26:1 respectively. The higher strain rates of both the static and vibrating cantilever beam could be the primary reason for the slightly higher dynamic modulus values (John et al, 2013).

2.5 CRACK IDENTIFICATION

In this project a method for crack identification in beam structures is determined by analysing the fundamental mode of cracked and uncracked cantilever beam is proposed. The beam is considering as continuous to the left and right of the crack and applying boundary condition as the characteristics equation in terms of natural frequencies and mode shape are determined for free transverse vibrations. Non-destructive inspection techniques are generally used investigate the critical changes in the structural parameters so that an unexpected failure can be detected (Mansour Peimani et al, 2007).

Detection of crack in a beam is performed in two steps but in this experiment considered the step two which is for each position of the crack in each element depth of the crack is varied. Modal analysis for each position and depth is then performed to find the natural frequencies of the beam (Nahvi, 2005). A conventional methods based on model updating concepts prove sufficient for the damage localization and just two frequencies are required if only one crack is present (Lamonaca et al, 2001).

Furthermore recent works pointed out that crack identification is not the same as the more general and complex problem of model reconstruction where the whole stiffness distribution in a structure is sought for (Vestroni et al, 1996). Finally experimental works show that if the damage severity due to a crack is defined as the ratio between the design strength over the plastic strength then the expected limit change in frequency is of about 10 %, so a meaningful identification method should be able to detect cracks using frequency changes well below this limit (Chen et al, 1995).

2.5.1 Time domain

The traditional way of observing signals is to view them in the time domain. The time domain is a record of what happened to a parameter of the system versus time. For instance, Figure 2.8 shows a simple spring mass system where we have attached a pen to the mass and pulled a piece of paper past the pen at a constant rate. The resulting graph is a record of the displacement of the mass versus time, a time domain view of displacement. Such direct recording schemes are sometimes used, but it usually is much more practical to convert the parameter of interest to an electrical signal using a transducer.

Transducers are commonly available to change a wide variety of parameters to electrical signals. Microphones, accelerometers, load cells, conductivity and pressure probes are just a few examples. This electrical signal, which represents a parameter of the system, can be recorded on a strip chart recorder as in Figure 2.9. We can adjust the gain of the system to calibrate our measurement.

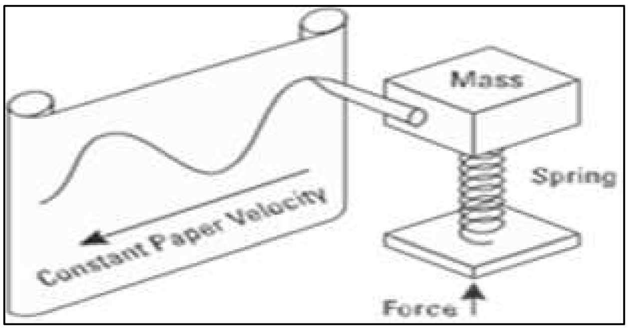

Figure 2.8: Simple spring mass system

Source: The Fundamental of Signal Analysis

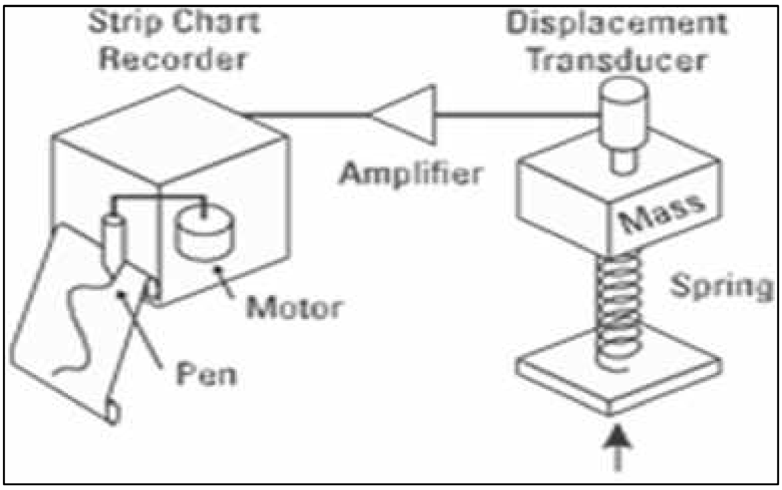

Figure 2.9: Electric signal

Source: The Fundamental of Signal Analysis

The desire parameter must be converted to the displacement of the recorder pen. Usually, the easiest way to do this is through the intermediary of electronics. However, even when measuring displacement we would normally use an indirect approach. The reason is primarily because the system in Figure 2.9 is hopelessly ideal. The mass must be large enough and the spring stiff enough so that the pen’s mass and drag on the paper will not affect the results appreciably.

In addiction the deflection of the mass must be large enough to give a usable result; otherwise a mechanical lever system to amplify the motion would have to be added with its attendant mass and friction. With the indirect system a transducer can usually be selected which will not significantly affect the measurement.

This can go to the extreme of commercially available displacement transducers which do not even contact the mass. The pen deflection can be easily set to any desired value by controlling the gain of the electronic amplifiers. This indirect system works well until our measured parameter begins to change rapidly.

Just because of the mass of the pen and recorder mechanism and the power limitations of its drive, the pen can only move at finite velocity. If the measured parameter changes faster, the output of the recorder will be in error. A common way to reduce this problem is to eliminate the pen and record on a photosensitive paper by deflecting a light beam. Such a device is called an oscillograph.

Since it is only necessary to move a small, light-weight mirror through a very small angle, the oscillograph can respond much faster than a strip chart recorder. Another common device for displaying signals in the time domain is the oscilloscope. Here an electron beam is moved using electric fields (Serge Lalonde et al, 2000). The electron beam is made visible by a screen of phosphorescent material. It is capable of accurately displaying signals that vary even more rapidly than the oscillograph can handle. This is because it is only necessary to move an electron beam, not a mirror. The strip chart, oscillograph and oscilloscope all show displacement versus time. We say that changes in this displacement represent the variation of some parameter versus time.

2.5.2 Frequency domain

It was shown over one hundred years ago by Baron Jean Baptiste Fourier that any waveform that exists in the real world can be generated by adding up sine waves. We have illustrated this in Figure 2.5 for a simple waveform composed of two sine waves. By picking the amplitudes, frequencies and phases of these sine waves correctly, we can generate a waveform identical to our desired signal (Bendat et al,1971).

Conversely, real world signal can be break down into these same sine waves. It can be shown that this combination of sine waves is unique; any real world signal can be represented by only one combination of sine waves. Figure 2.10 is a three dimensional graph of this addition of sine waves. Two of the axes are time and amplitude, familiar from the time domain. The third axis is frequency which allows us to visually separate the sine waves which add to give us our complex waveform (Julian et al, 1971). If we view this three-dimensional graph along the frequency axis we get the view in Figure 2.10. This is the time domain view of the sine waves. Adding them together at each instant of time gives the original waveform. However, if we view our graph along the time axis as in Figure 2.10, we get a totally different picture.

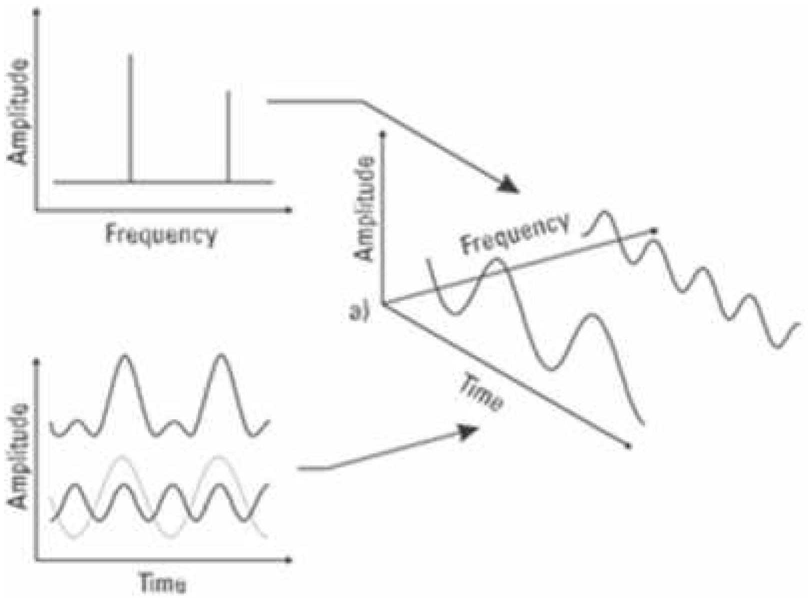

Figure 2.10: The relationship between the time and frequency domain

Source: The Fundamentals of Signal Analysis

This is an axis of amplitude versus frequency, what is commonly called the frequency domain. Every sine wave that separated from the input appears as a vertical line. Its height represents its amplitude and its position represents its frequency. Since we know that each line represents a sine wave, we have uniquely characterized our input signal in the frequency domain.

This frequency domain representation of our signal is called the *spectrum* of the signal. Each sine wave line of the spectrum is called a component of the total signal. Since one of the major uses of the frequency domain is to resolve small signals in the presence of large ones, let us now address the problem of how we can see both large and small signals on our display simultaneously. If the fundamental was set to full scale on a four inch (10 cm) screen, the harmonic would be only four thousandths of an inch (0.1 mm) tall. Obviously, we could barely see such a signal, much less measure it accurately. Yet many analysers are available with the ability to measure signals even smaller than this. Since to be able to see all the components easily at the same time, the only answer is to change our amplitude scale.

A logarithmic scale would compress our large signal amplitude and expand the small ones, allowing all components to be displayed at the same time. Alexander Graham Bell discovered that the human ear responded logarithmically to power difference and invented a unit, the Bel, to help him measure the ability of people to hear (Allan et al, 1971).

One tenth of a Bel, the deciBel (dB) is the most common unit used in the frequency domain today. A table of the relationship between volts, power and dB is given in Figure 2.8. From the table we can see that our 0.1% distortion component example is 60 dB below the fundamental. If we had an 80 dB display as in Figure 2.9, the distortion component would occupy 1/4 of the screen, not 1/1000 as in a linear display. It is very important to understand that we have neither gained nor lost information; we are just representing it differently. We are looking at the same three-dimensional graph from different angles. This different perspective can be very useful.

2.6 THEORETICAL VIBRATION ANALYSIS FOR IDENTIFICATION OF CRACK

A cantilever beam with a transverse surface crack of depth „a1‟ on beam of width „B‟ and height „W‟ is considered for the current research.(Fernando et al, 2011) The beam is subjected to axial force (P1) and bending moment (P2) as shown below on Figure 2.11 which gives coupling with the longitudinal and transverse motion. The presence of crack introduces a local flexibility, which can be defined in matrix form, the dimension of which depends on the degrees of freedom. Here a 2x2 matrix is considered.

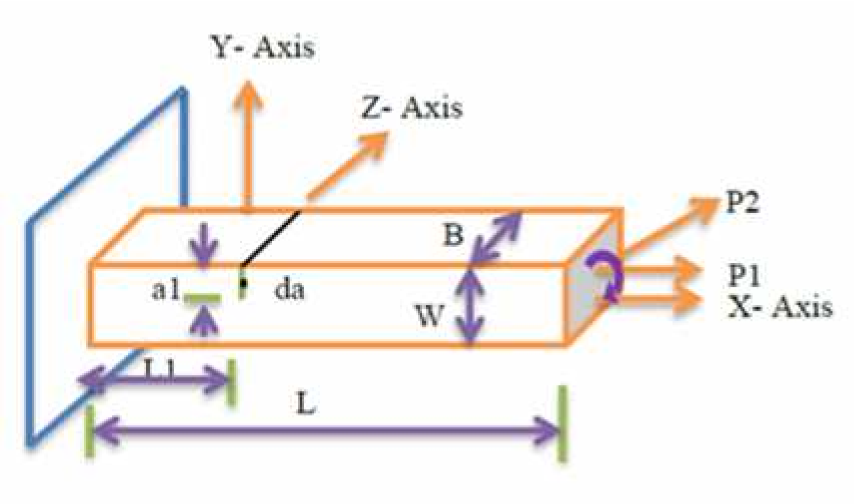

Figure 2.11: Geometry of Cracked Cantilever Beam

Source: Fernando et al, Damage detection, 2011

2.7 CONCLUSION

This chapter presents the detail information about the process of the project and also an overview about whole project. In this chapter, the suitable experiment that should be applied is modal testing since it relates the natural frequency and the phase or mode shape together in order to detect the crack on the structures. The description of the beam provides is described in this chapter followed by the literature analysis. Literature analysis contains the information about the sources gained and also related information that could be useful in order to complete the project.

CHAPTER 3

METHODOLOGY

3.0 INTRODUCTION

This chapter discusses about process of development the suggested cantilever beam from the journal and reference provided. The sketches of specimen are shown in Figure 3.1 to Figure 3.4 for health, 10%, 20% and 50% depth penetration respectively. The process started with sketching the general idea for the design.

Secondly, the developments of sketching by refer to the journal or article. It is important to determining the exact dimension of the cantilever beam, method or procedure that applied to the beam, the handling system style, the suitable point of the impact hammer and the workplace where experiment will be held. Then, full scale for all proposed designs was sketched and will be checked by the supervisor. Technical specifications for all models also had discussed in this chapter. Lastly, all the design will be analysed by using Algor software.

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3.1 CONSTRUCTION OF CANTILVER BEAM

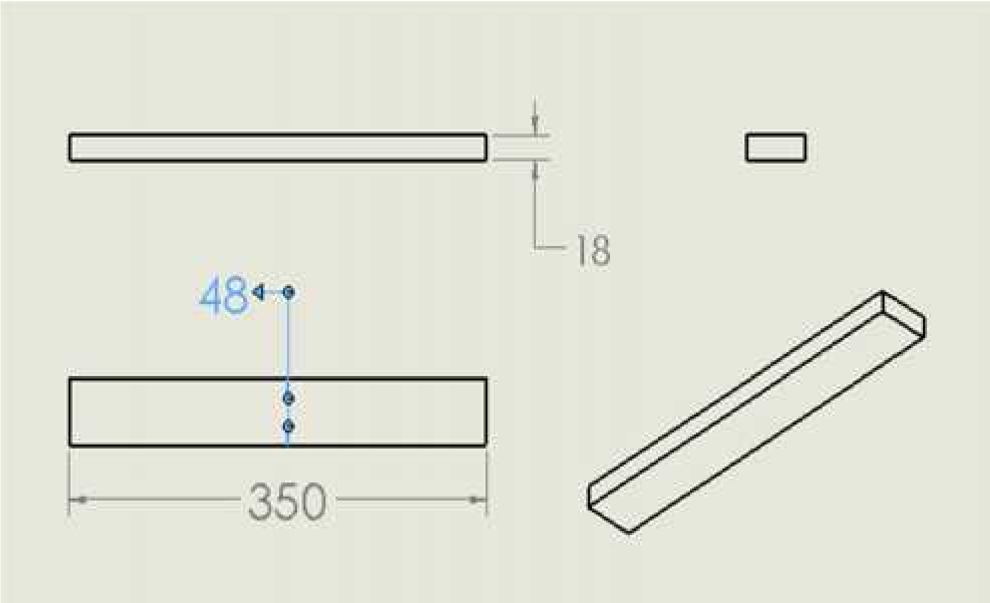


Figure 3.1: Drawing of Specimen 1 (healthy beam)

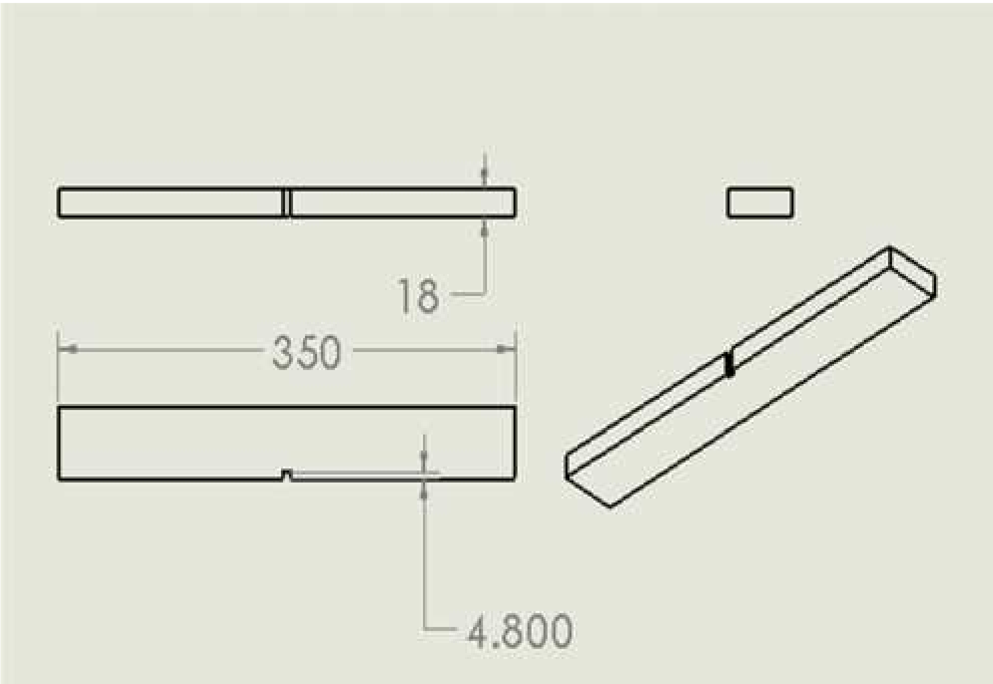


Figure 3.2: Drawing of specimen 2 (10% crack)

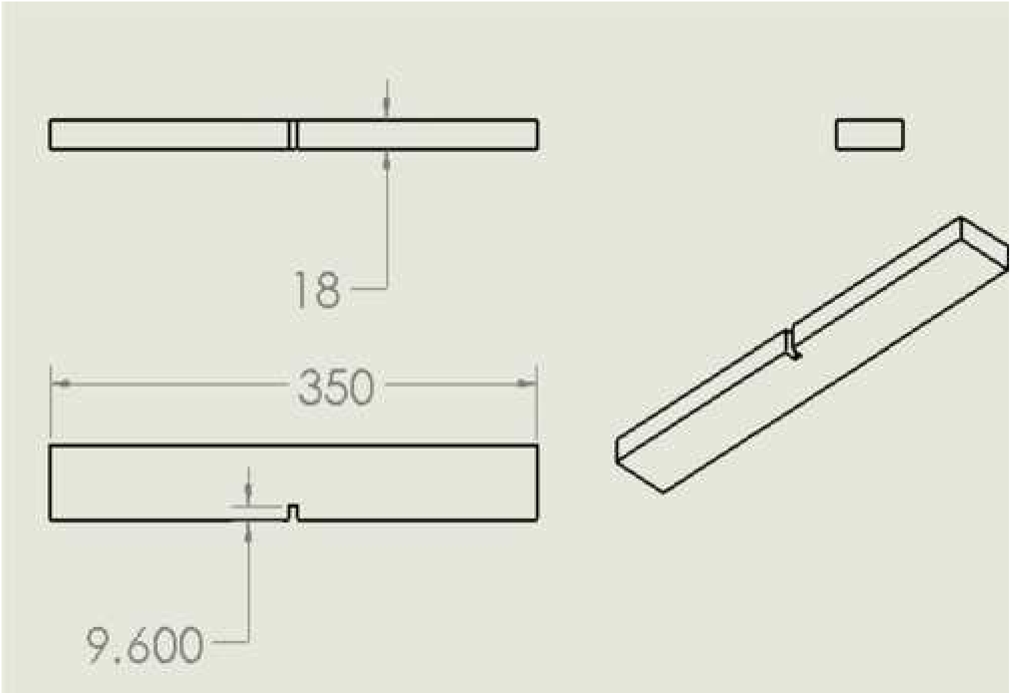


Figure 3.3: Drawing of specimen 3 (20% crack)

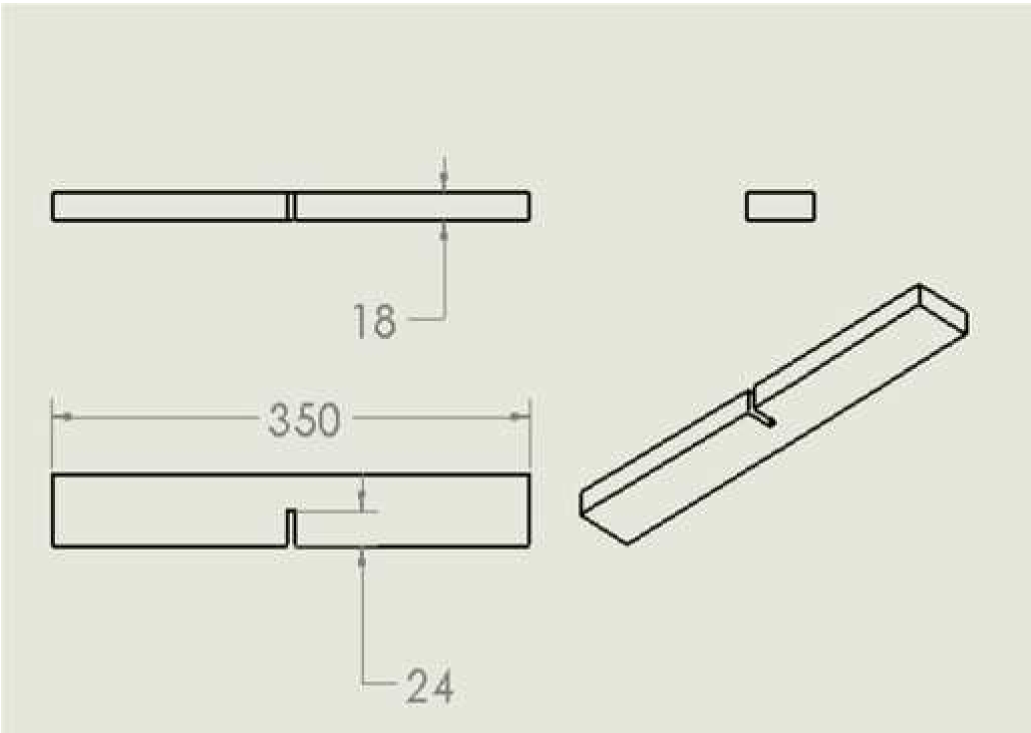


Figure 3.4: Drawing of specimen 4 (50% crack)

In this project, the design consideration in modal testing play an important role because it totally affect the results obtained at the last of experiment that be held. So, design that will be chose to be the best design is mild steel beam about 1400 mm in length, 50mm in height and 20mm in width. Then the specimen will be divided into four specimen which about 350mm in length while the value of width and height is still the same.

3.1.1 Specification of the specimen

i. First specimen will be 350 mm in length, 48 mm in height and 18 mm in width. The specimen also did not have any crack on it since to capture the real natural frequency and phase before applying any crack on it.

ii. Second specimen will be 350 mm in length, 48 mm in height and 18 mm in width. The specimen will have a crack about 10 % in depth which about 4.8 mm in depth.

iii. Third specimen will be 350mm in length, 48 mm in height and 18 mm in width. The specimen will have a crack about 20 % in depth which about 9.6 mm in depth.

iv. Fourth specimen will be 350 mm in length, 48 mm in height and 18 mm in width. The specimen will have a crack about 50 % in depth which about 24 mm in depth.

v. The entire four specimens will be marked into seven elements each in order to get the accurate and precise results. The location of depth also will be in the center for each specimen since the location of the depth is constant.

3.2 SPECIMEN PREPARATION

3.2.1 Band saw

Designing a cantilever beam, dimensions should be made precisely in order to made the experiment tally to the objective and scope of the project. Based on the journal,the dimension chosen is as 1400mm in length and divided by four,so the length just now is 350 mm each,while the height is 48 mm and the width is 18 mm. To make a good cut at the vertices of the beam,the beam must cut using the proper machine so that the length is exactly at 350 mm in length. Thats why bandsaw is chosen as it is a power tools which uses a blade consisting of a continuous band of metal with teeth along one edge to cut various workpiece and various length specified.

This machine also produces unifrom cutting action as a result of an evenly distributed tooth load. It commonly used in woodwroking, metalworking and also used for cutting a avariety of other materials and for sure particularly useful for cutting irregular or curved shapes but also can be used to produce straight cuts.

3.2.2 Wire-cut

This kind of process is important in order to get the exact crack depth in the specimen. As we know, the basic wire cut process or in other words is EDM process is really quite simple. EDM wire cutting uses a metallic wire to cut a programmed contour in the workpiece. An extrusion dies and blanking punches are very often machined by wire cutting. Cutting is always through the entire workpiece.

Firstly,to start machining it is necessary to drill a hole in the workpiece or start from the edge. On the machining area, each discharge sreates a crater in the wrokpiece and an impact on the tool. The wire can be inclined thus making it possible to make parts with taper or wth different profiles at the top and bottom. There is never any mechanical contact between the electrode and workpiece. The wire is usually made of brass or copper and the diameter is between 0.1 or 0.3 mm.

3.2.3 Fabrication techniques

There are procedures and some method to make this modal testing experiment. The procedures are stated below;

i. The beam will be choosing as the length will be 1400 mm in length, 50 mm in height and 20 mm in width.
ii. The specimen chosen will be divided into four work piece as the dimension still the same but differ in length. The new length is 350 mm. This specimen will be divided with handsaw machine.
iii. Next, the specimen will be let to have crack on it but only three specimens will have it which the other one will let as uncracked work piece. The crack will be differ in depth which the first one will have 4.8 mm depth, the second one is 9.6 mm and third specimen will have 24 mm in depth.
iv. The crack that specimen will have is by the wire cut process in CNC lab in order to get the precise and accurate crack on the specimen.
v. The entire specimen will be divided into seven elements or 7 points as to know different in the natural frequency and mode shape for each point on the work piece.
vi. The entire four specimens will be clamp onto the table provided in the lab and accelerometer will be attached on it.
vii. The accelerometer will be connected to the DAQ tools as it captures the vibration signal and will transmit it into the DASY lab software.
viii. The block diagram will be arranged based on objective of the project on the DASY lab software so that the result will be obtained and the data will be tabulate automatically onto table.
ix. The impact hammer will give an excitation forces to the first specimen which did not have crack on it to the first till the 7 points marked on the structures. Each point will be hit by impact hammer about 5 times to get the average of forces. The natural frequency and the mode shape will be observed an the data will be captured.
x. Step above will be repeated to another three specimen which having a crack on it, but differ on depth.
xi. The data will be collected for the four specimens and the analysis will be done.

3.3 DATA ACQUISITION AND SIMULATION

Recently software are developed so well and mostly software also been used in experiment which made the experiment so easily to be held and the tools,procedure can be handled without any errors because there are certain software that can made virtual experiment.

This software is related to the Measurement & Automation which the data will be synchronize towards it. First step is at modules toolbox ,click at the inputs/outputs folder, then click at the NI-DAQmx folder. Choose the analog input. After that, at the menu toolbar, choose the measurement,go to hardware setup , NI-DAQmx and click the synchronization with MAX configuration. This will make the setting of the tools of DAQ in Measurement & Automation will be transferred and synchronize automatically with the Dasy lab. Go to the measurement toolbar again, measurement setup, NI-DAQmx and click at the measurement setup. At this we can setting and adjust all the value like sampling rate and also the block size.

Besides this setting also can be made in other function. Go to the measurement at the menu bar, time bases, instruNet and click time base setting. Construct the block diagram in the workspace provided by using module on it like y/t chart,relay,data trigger,data window,fft,arithmetic and so on. Figure 3.5 shows the block diagram used in Dasy lab for the experiment.

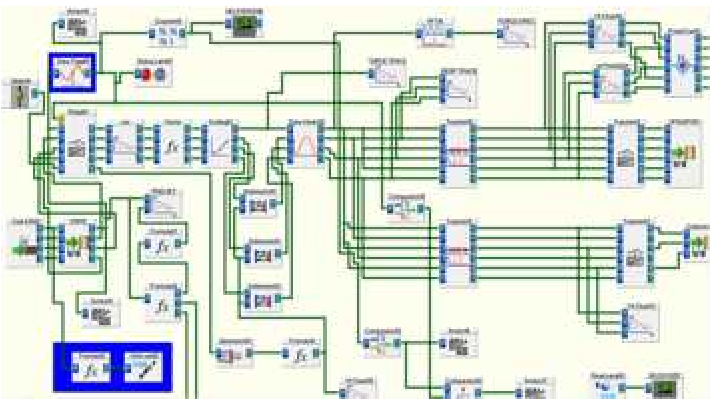


Figure 3.5 : Block Diagram

3.3.1 Algor

In this Algor we will find the entire requirement to build a simulation like a system templates, material data, geometry files and other objects provided in the Toolbox on the left side of the window. The Project Schematic area will contain the analysis system and project that we build. First, import the specimen in the STEP format.

Then, the specimen will appear in workspace. Then click one end of surface in order to make it fixed and the beam will be a cantilever beam. At the left side, there are element type, element definition and also material. Right click each of them by change it to the beam for element type, and material change it to AISI 1018 cold drawn since it is typical name for mild steel beam. At that menu bar, click mesh and generate mesh. After that, click simulation button and the simulation result will appear soon. The example of simulation result is shown below on Figure 3.6.

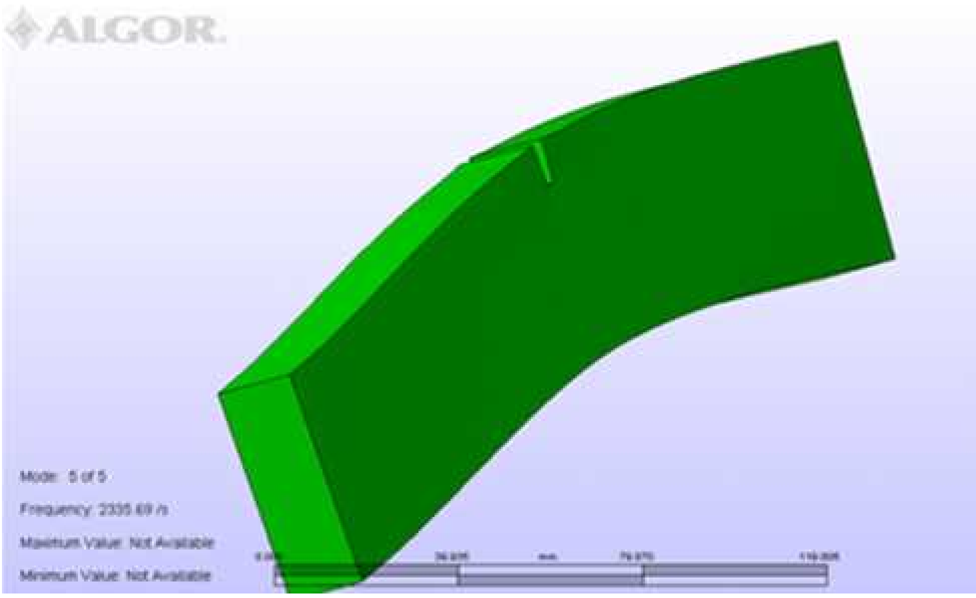


Figure 3.6: Graphic Display

3.4 TEST RIG AND TOOLS PREPARATION

The experiment involved the usage of measurement tools which is accelerometer and also use of impact hammer for impact testing. The tests were done to get the acceleration signal from cantilever beam with different type of crack at different point. A DAQmx measurement device was used as a test rig for this experiment and shown on Figure 3.7.

Figure 3.7: DAQmx device

The sensor which is accelerometer shown on Figure 3.8 was located at few points on the cantilever beam according the test conducted. The sensor must touch the cantilever beam in order to measure the acceleration signal. Furthermore, to achieve maximum detection, the grease or sticky gum for accelerometer was used between the sensor and the beam. The sensor was glued at one point of the beam. The beam must be divided into 8 points so that the signal can be measured by different points. The impact hammer was used to give an excitation forces to produce a vibration forces towards the beam that clamped.

Figure 3.8: Tri Axial Accelerometer

The value of forces given to the beam by the impact hammer shown on Figure 3.9 was limited using a software called Dasy lab and it will make sure the forces given to each point by the impact hammer almost the same and never over the limit

Figure 3.9: Impact hammer

3.5 CONCLUSION

This chapter discussed the work progress and the working procedure in developing the designs and also how the experiment are been held of proposed cantilever beam. This methodology also discussed the expected condition where physically might be one of a factor that can be affecting the result obtained in the final of the experiment which is the natural frequency or mode shape will be totally changed, based on material and dynamic behaviour of the structures chosen.

CHAPTER 4

RESULTS & DISCUSSION

4.0 INTRODUCTION

As mentioned in the previous chapter, two tests were conducted to achieve the objectives for this project. Note that, some of the result from this experiment shows the almost same pattern as other test. Next topics show the result of all the experiments.. Impact testing is one of the modal testing methods where it can be done manually, thus lower the cost for experiment process.

One of the important characteristic of this technique is it can be used to sense only specific and small defect, by recognizing the pattern of the signals appeared. Besides, this method is noise tolerant; which mean, the data is free from other unwanted signal. This has been proved by two simple tests where the accelerometer is placed to the beam without any forces and without touched anything. No result shown by the recording software for both tests.

It is vital to make sure the signals were in the stable condition before 'recording' can be started. Two important precaution steps need to be applied. First, the impact hammer must be connected properly to the DAQ devices so that the signal will be recorded well. Second, the block diagram must be synchronized to the data neighbourhood in the DAQ software so that the block diagram will function well according to the DAQ system. The data should be taken about five times is better since this step is to eliminate any unwanted vibration that may occur when the beam is clamped only using G clamp.

The sample rate value and block size needs to be set in the software setting before recording can be done. The proper selection of sample rate and block size value is necessary to allow better form of signals to be shown. If the value is too high, no signals or hits maybe recorded. Meanwhile if the force value is too low, the signals may appear as continuous signal instead of burst signal. Note that, burst signal form is better in term of recognizing the pattern of the signals.

4.1 DISCUSSION OF RESULTS OF MODAL TESTING

Frequency Response Functions (FRFs) obtained from modal testing was analysed using ME Scope .A total of 21 and 24 modes were extracted from the FRFs of the first and second experiments, respectively. By the help of the mode shape animation part of Me Scope, these mode shapes are animated .By investigating these mode shapes, it is realized that some of the mode shapes was computational modes and are not likely to be replicated by structural analysis.

Since the Me Scope software was verified using a cantilever beam's synthetically generated experimental data, it is certain that there are no formulation or programming errors in Me Scope. The computational modes are excluded from the model updating process. Modal tests that were conducted on the test frame were not possible to replicate due to laboratory and scheduling constraints. The reason of obtaining unreasonable (computational) mode shapes can be explained with the number of accelerometers used in modal testing. Equipment used for modal data acquisition (or dynamic analyser) has only 2 input channels, which are used for one load transducer and one accelerometer. Since there was only one channel for accelerometer, in order to obtain mode shapes, the accelerometer was roved over 7 reference points on the beam.

Obtaining all mode shapes correctly using a single accelerometer is not possible, and a larger number of accelerometers are needed in order to obtain healthy results. One of the accelerometers should be stationary (at the driving point) and the other accelerometer(s) should be moved over reference nodes sequentially.

The reference accelerometer should be used for determining the sign of the mode shapes and for the magnitude of the modal scaling factor.. Since there was only one channel available for acquiring response of the model in this study, it is assumed that if two accelerometers were used, modal scaling factor obtained in two tests would have been equal and for the reference accelerometer there would be no sign change in the mode shape coefficient. Natural frequency and damping factor can be correctly obtained even if only one accelerometer is used in the modal testing. However, this does not guarantee that the mode shapes are obtained correctly. Although some of the mode shapes may be correctly obtained, some mode shapes may be erroneous.

4.1.1 Frequency domain graph

Figure 4.1 to Figure 4.4 shows the results from the first experiment. Total frequency and magnitude of signal recording time are presented. The impact testing is starting to hit the beam for five average hits before the Dasy Lab software collect the data. This to ensure the signals measured are stable throughout the data collecting process. This condition applied for all the tests.

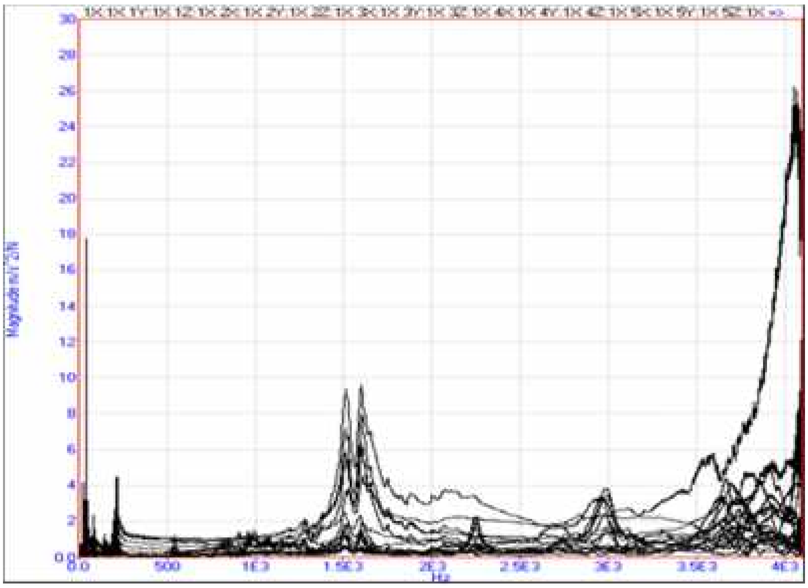


Figure 4.1: Frequency domain graph for 0% crack beam

This graph was obtained by Me scope software which it interpret data capture form Dasy lab software. The graph is frequency versus amplitude. As we looked from the Figure 4.1, there are some differences that we can observed that for healthy cantilever beam, there are several peaks appear and the most obvious peaks is peak at number 3,compared to the other peaks. All the peaks shows the natural frequency of the beam when the beam was excited by impulse from impact hammer.

This graph was obtained by Me scope software which it interpret data capture form Dasy lab software. As we looked from the Figure 4.2, there are some differences that we can observed that for 10% crack cantilever beam, there are several peaks appear and the most obvious peaks is peak at number 3,compared to the other peaks. Based on the most obvious peaks which is peaks number 3, the peak is shifted a little compared to the peak number 3 of the healthy beam, and same goes to the another peaks.

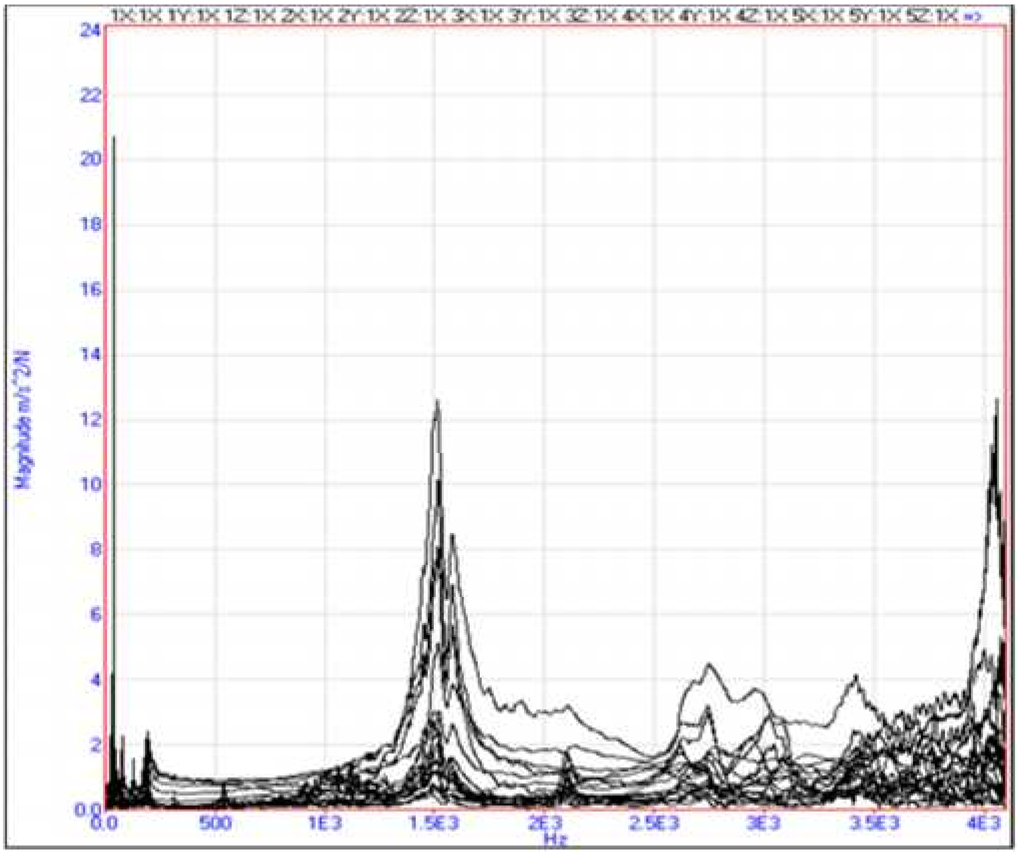


Figure 4.2: Frequency domain graph for 10% crack beam

Figure 4.3 was obtained by Me scope software which it interpret data capture form Dasy lab software. As we looked from the Figure 4.3, there are some differences that we can observed that for 20% crack cantilever beam, there are several peaks appear and the most obvious peaks is peak at number 3,compared to the other peaks. Based on the most obvious peaks which is peaks number 3, the peak is shifted more compared to the peak number 3 of the healthy beam, and same goes to the another peaks.

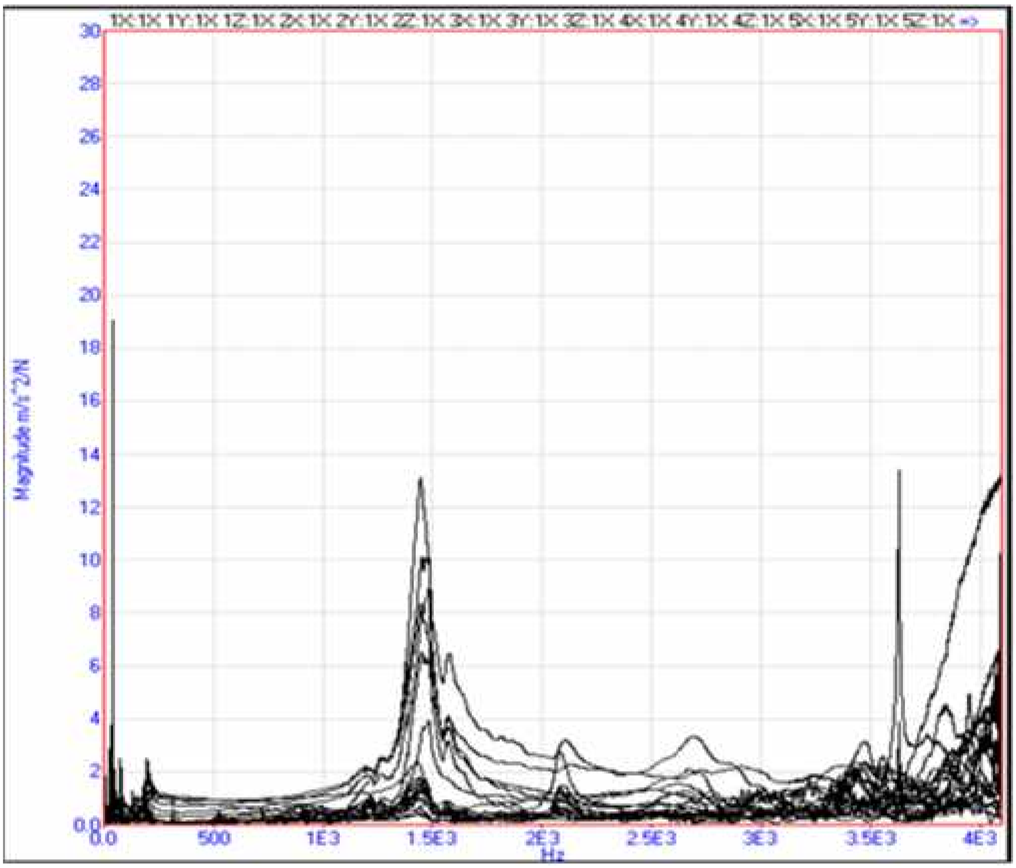


Figure 4.3: Frequency domain graph for 20% crack beam

Figure 4.4 was obtained by Me scope software which it interpret data capture form Dasy lab software. As we looked from the Figure 4.4, there are some differences that we can observed that for 50% crack cantilever beam, there are several peaks appear and the most obvious peaks is peak at number 3,compared to the other peaks. Based on the most obvious peaks which is peaks number 3, the peak is shifted most compared to the peak number 3 of the healthy beam, and same goes to the another peaks.

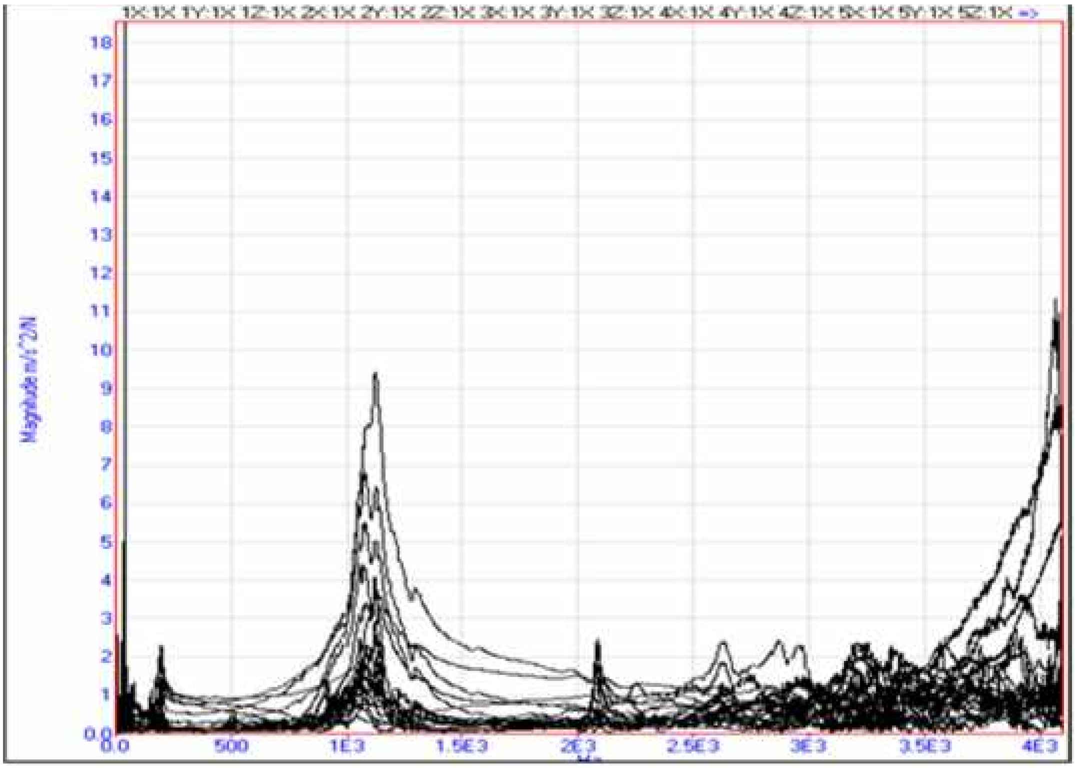


Figure 4.4: Frequency domain graph for 50% crack

4.1.2 Frequency domain table

As mentioned earlier, this experiment is the main part for this project. For this test, natural frequency and mode shape are monitored in order to determine whether there are changes if the beams are different in condition. Measurement is taken at seven different locations on the beam. For each measurement, 5 times of forces were taken to be analyzed; from about 600 signals that have been recorded using the computer for each measurements.

These signals were already filtered and analyzed. The filtering process was done using block diagram in the Dasy lab software where only good data were allowed to be viewed. Based on the reading provided in the Table 4.1 below, as we can see from mode 1 to mode 5, the reading is decreased a little which is starting from the healthy beam or 0% crack beam till the 50% beam. It means that the natural frequency is shifted when the beam is having a crack, shows that if the crack exists on the beam are deeper so the shifted natural frequency will be greater.

From all the mode stated in the table which is mode 1,mode 2,mode 3,mode 4 and mode 5,the mode chosen for detecting the crack exist on the beam is the mode 5. Reason why the mode 5 is chosen compared to another mode is the mode 5 is the 1st bending mode in y direction and it is significant to the opening of the crack exists of the beam. The impulse from the impact hammer is given according to the y direction and the mode 5 is move more significant and obvious compared to another mode which is not same direction with the y direction. In this experiment we are looking for the two of dynamic characteristics of the beam which is the mode shape and the natural frequency of the beam.

For the natural frequency, data extracted and analysed show that the natural frequency is really shifted when the crack is exists on the beam compared to the natural frequency of the healthy beam. Then the mode is referred to make sure which is the mode will give an obvious proof related to the shifted natural frequency in order to detect whether the crack is exists on the beam or not. The mode will be chose according to the direction of the opening of the crack and the impulse direction given by impact hammer.

Table 4.1: Frequency domain table for all specimens

Mode	**Natural Frequency**			
	0 %	**10%**	**20%**	**50%**
1	37.5	36.8	36.4	34.7
2	207	202	192	189
3	1600	1510	1230	1130
4	2150	2100	2097	2080
5	2980	2750	2695	2630

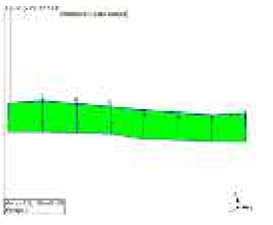
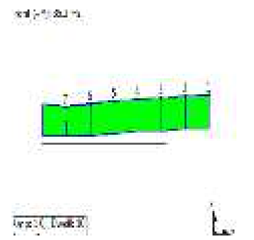
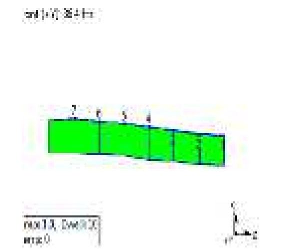
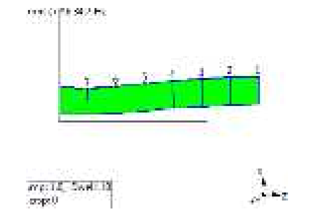
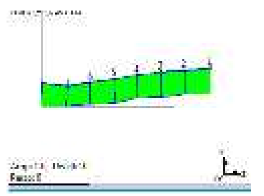
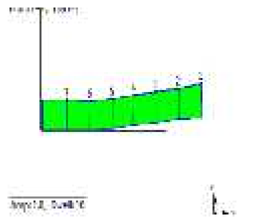
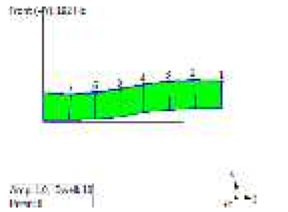
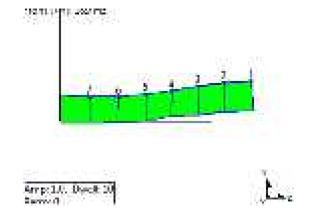
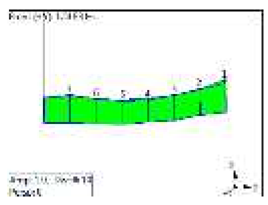
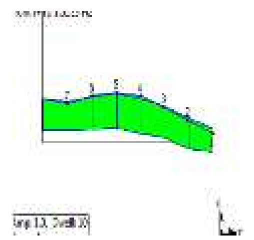
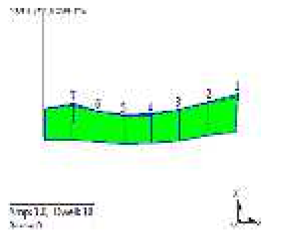
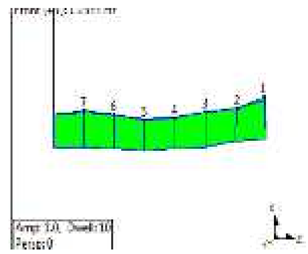
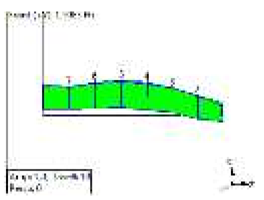
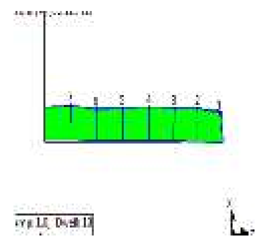
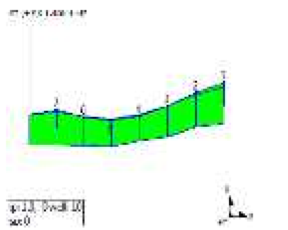
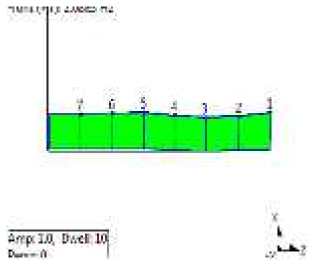
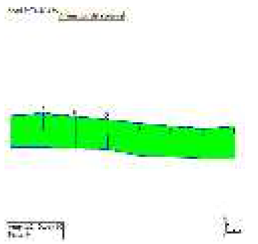
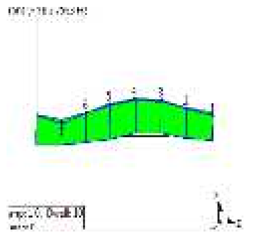
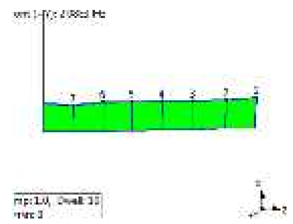
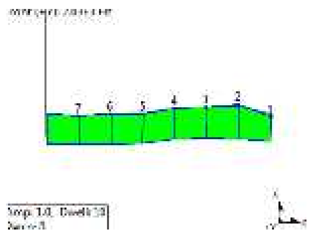
4.1.3 Mode shape table

Table 4.3 shows the movement of the mode shape of the four different kind of the beam which is 0% beam, 10% crack beam, 20% crack beam and 50% crack beam.

The mode is specified by mode 1 till mode 5.From mode 1 till mode 5, the movement is totally different and the mode which is significant to the crack direction will be chosen.

So from the 5 mode given, the mode 5 will be chosen. For mode 1,it move just a little bit to the up and down, mode 2 is twisted a little, mode 3 is bending up and down, mode 4 is torsion mode and twisted a lot at the front of the beam and mode 5 are bending at the middle to the left and right. From the five mode identified in this experiment, mode 3 is chosen is because the mode 3 is too significant and it also the first mode of bending mode in y direction which same direction to the crack exist on the beam. Since the natural frequency in the mode 3 also too obvious, so it is proved that the beam having a crack on it.

Table 4.3: Mode Shape table for all specimens

Mode	Mode Shape			
	0 %	10%	20%	50%
1				
2				
3				
4				
5				

4.2 MODAL SIMULATION

Results from simulation come in graph for natural frequency and results for mode shapes come in picture from simulation.

4.2.1 Frequency domain table

Table 4.2 is provided to show the value of natural frequency of the beam when the beam is simulated in the Algor software. Based on the data in the table, we can see that the value of natural frequency by mode 1 till mode 5 is decreased which is it show that the natural frequency is shifted. The most greater in decrease of the value of natural frequency is in the mode 3,4 and 5.

From the mode 3, 4 and 5, mode 5 is chosen because for the mode 3, the mode is bending to the left and right only while for the mode 4, the mode is twisted also to the left and right but for mode 5, the mode is bending towards y direction which is up and down direction which is significant to the crack direction.

When the impulse is excited from the impact hammer in y direction, it will altered the mode shape and the mode shape in the bending mode will be obviously altered compared to the torsion mode. Mode 5 in the simulation or other words is the 1^{st} bending mode in y direction is chosen since this kind of mode is parallel to the crack direction.

Table 4.2: Frequency domain table for all specimens

Mode	**Natural Frequency**			
	0 %	**10%**	**20%**	**50%**
1	208.93	165.895	165.934	162.889
2	462.435	431.972	427.715	388.328
3	1400.3	1021.21	1022.98	959.118
4	2415.05	1650.12	1642.20	1549.48
5	2718.95	2421.91	2335.69	1821.97

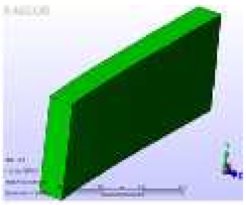
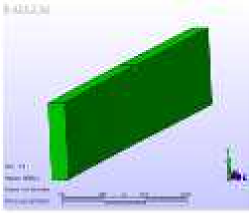
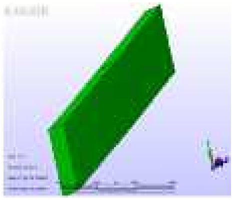
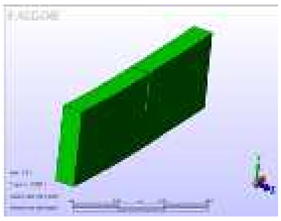
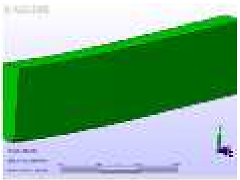
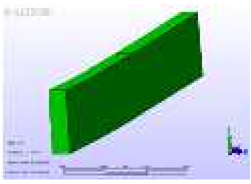
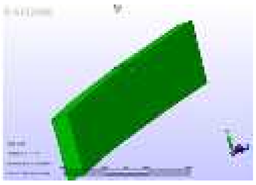
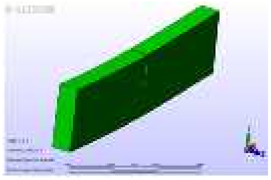
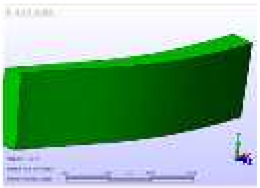
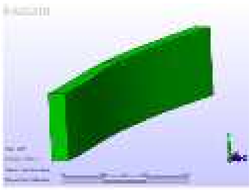
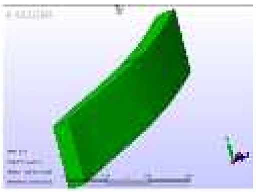
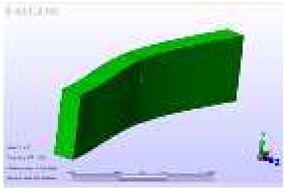
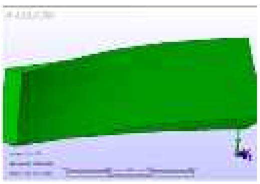
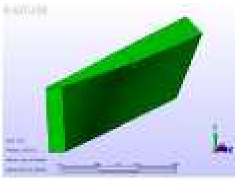
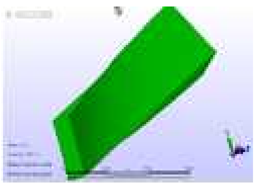
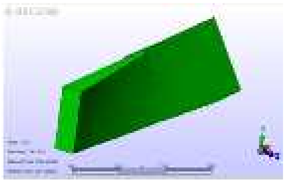
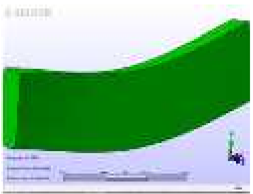
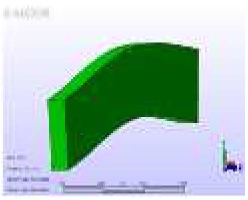
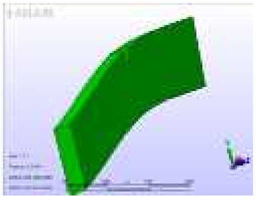
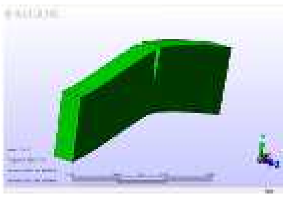
4.2.2 Mode shape table

Table 4.4 shows the movement of the mode shape of the four different kind of the beam which is 0% beam, 10% crack beam, 20% crack beam and 50% crack beam.

The mode is specified by mode 1 till mode 5.From mode 1 till mode 5, the movement is totally different and the mode which is significant to the crack direction will be chosen.

So from the 5 mode given, the mode 5 will be chosen. For mode 1,it move just a little bit to the up and down, mode 2 is twisted a little, mode 3 is bending at the middle to the left and right, mode 4 is torsion mode and twisted a lot at the front of the beam and mode 5 are bending up and down. From the five mode identified in this experiment, mode 5 is chosen is because the mode 5 is too significant and it also the first mode of bending mode in y direction which same direction to the crack exist on the beam. Since the natural frequency in the mode 5 also too obvious, so it is proved that the beam having a crack on it.

Table 4.4: Mode Shape table for all specimen

Mode	Mode Shape			
	0 %	**10%**	**20%**	**50%**
1				
2				
3				
4				
5				

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 CONCLUSION

This study proved that modal testing technique can be used for crack identification. The technique offers great opportunity to have new approach of lower cost and time consuming for pipe and valve monitoring.

The dynamic parameters such as the natural frequency and inherent damping value of their components are very important in compliant structures. Modal testing is a non-destructive testing strategy based on vibration responses of the structural members.

In this paper, the application of experimental modal testing to various beams based on the impact hammer excitation is attempted to assess the natural frequency, damping constant and associated mode shapes of these examples. The modal testing has proven to be an effective and non-destructive test method for estimation of dynamic characteristics of beams.

The results are very promising since the approach is capable of identifying and tracking all physical modes of interest even in difficult cases of closely spaced or even crossing modes due to changes (damage) in the structure. The proposed approach is applicable for both forced-vibration and output-only measurements and provides a tool for structural health monitoring. It is shown that accurate parameter estimates with coincidences intervals are estimated by means of the frequency domain Maximum Likelihood algorithm, while stochastic mode validation criteria, make the validation process more robust to measurement noise.

The mode tracking process is based on model comparison between subsequent measurements. Using the minimal distance between mode residue matrices, corresponding modes can be successfully determined even without the need of extensive spatial information, which is important for the implementation of many monitoring systems.

The tracking approach provides a small band re-estimation in the case of missing or wrongly estimated modes due to closely spaced or crossing modes not captured by the model during the broadband analysis. Eventually, it has been demonstrated that the proposed tracking approach still works for larger structural changes.

5.2 RECOMMENDATION

5.2.1 Applications

As the techniques used for crack detection are non-destructive in nature, so these techniques can be effectively used for online condition monitoring of engineering systems. The techniques developed for crack detection can be used for prediction of crack in flow lines, turbo machinery, nuclear plants and ship structures, biomedical engineering system.

5.2.2 Scope for Future Work

Analysis of Me scope system can be extended for localization and identification of crack in complex beam structures with multiple cracks. The complete analysis of the current research work is carried out based on the Euler beam like structure and it can be extended for Timoshenko beam like structure.

Cohonen network technique and Fuzzy Logic technique can be hybridized to propose another technique for identification of crack in beam like structure

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