A STUDY OF DYNAMIC CHARATERISTICS FOR CRACK IDENTIFICATION

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Thesis submitted to the Department of Mechanical Engineering
in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2013

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 1^{st} 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.

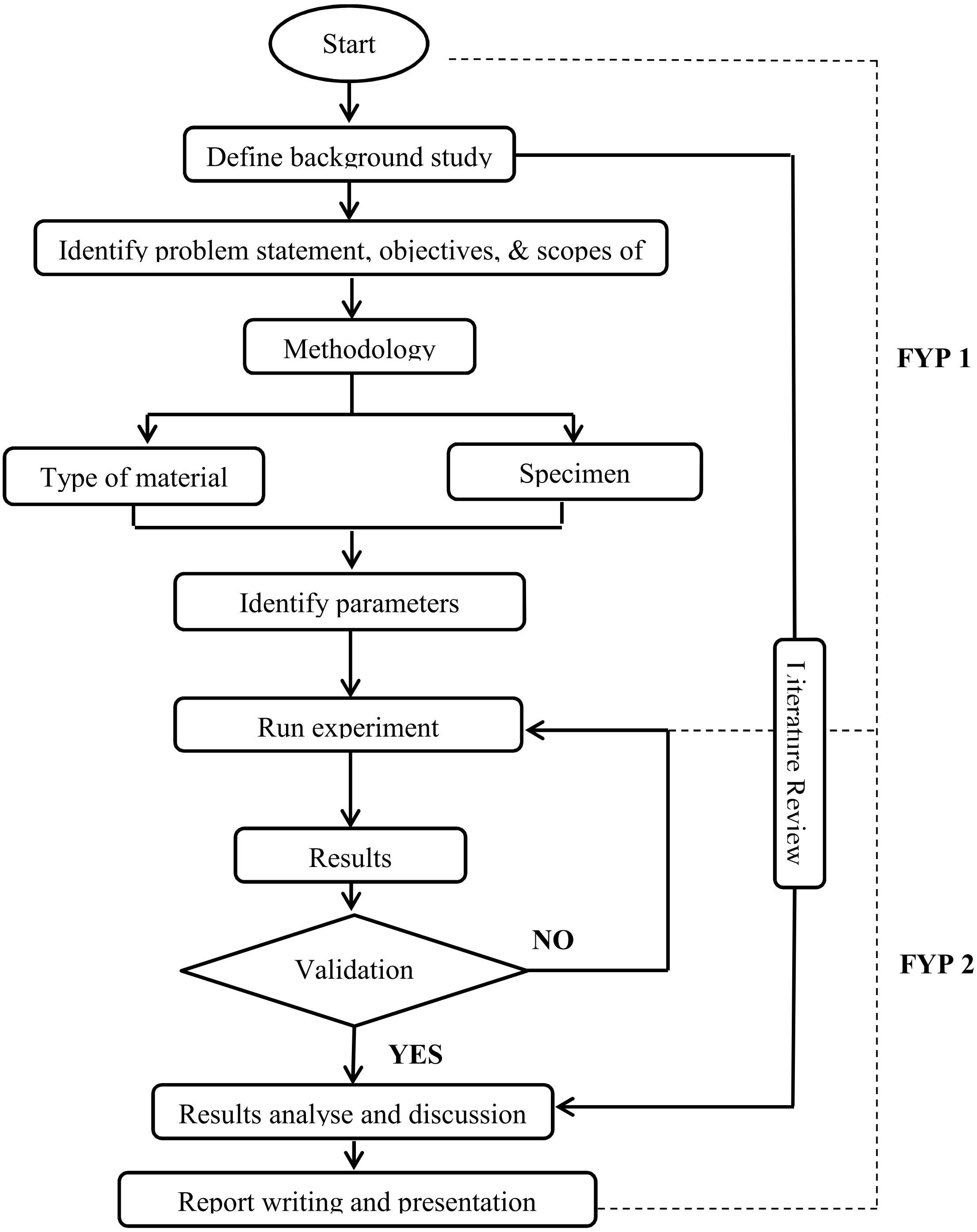

Figure 1.1: Project's Flow Chart

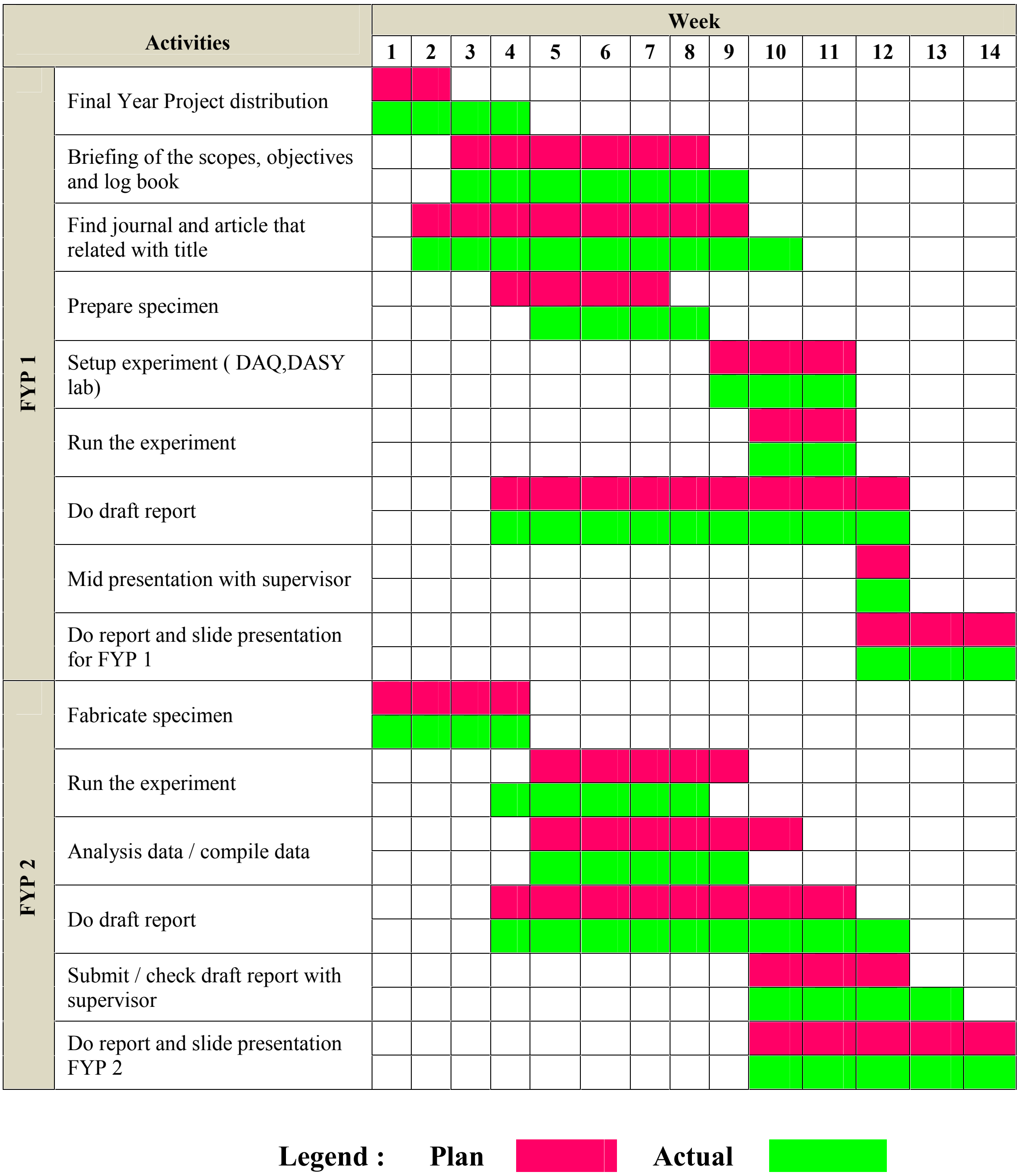

Figure1.2: Gantt chart FYP 1 & FYP 2

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.

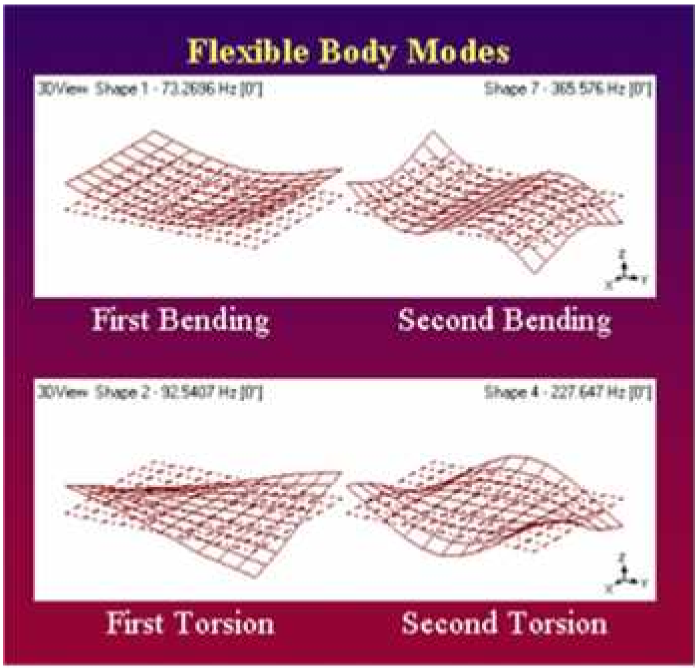

Figure 2.1: Flexible Body Modes

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.