



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**HYBRID VEHICLE (HV) CHASSIS VIBRATION SOURCES
DETECTION AND IDENTIFICATION USING FREQUENCY
DOMAIN ANALYSIS**

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Mechanical Engineering Technology (Automotive Technology) with Honours

by

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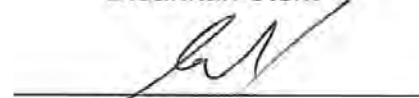
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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfilment of the requirements for the degree of Bachelor Degree of Mechanical Engineering Technology (Automotive Technology) with Honours. The member of the supervisory is as follow:


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ABSTRAK

Getaran adalah faktor penting yang perlu dipertimbangkan apabila berurusan dengan produk mekanikal. Ia boleh menjadi berguna dalam beberapa aplikasi tetapi kebanyakan masa ia boleh merosakkan sistem. Setiap reka bentuk kejuruteraan perlu mengambil kira toleransi getaran terutamanya dalam reka bentuk yang berputar bingkai badan. Untuk memperbaiki keadaan sistem, industri menggunakan analisis getaran kepada setiap jentera untuk memantau keadaan Mesin dan mengekalkannya. Jadi, kajian ini telah dijalankan dengan analisis getaran pada casis kenderaan menggunakan perisian Matlab untuk mentafsir spektrum FFT. spektrum itu akan ditafsirkan untuk frekuensi dan amplitud yang wujud pada casis sesuatu kenderaan hibrid.

ABSTRACT

Vibration is an important factor that should be considered when dealing with mechanical product. It could be useful in some application but most of the time it could harm a system. Every engineered design must consider the vibration tolerance especially in design that has rotating frame of body. To improve the condition of the system, industries adopt vibration analysis to every machinery in order to monitor the condition of a machine and maintain it. So, this study was carried out with vibration analysis on vehicle chassis using MATLAB software to interpret FFT spectrum. The spectrum would be interpreted for its frequency and amplitude that exists on the chassis of a hybrid vehicle.

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TABLE OF CONTENT

Declaration	i
Approval	ii
Abstrak	iii
Abstract	iv
Acknowledgment	v
Table of Content	vi
List of Figures	viii

CHAPTER 1: INTRODUCTION

1.0	Introduction	1
1.1	Background	1
1.2	Problem Statement	2
1.3	Objectives	3
1.4	Scope	4

CHAPTER 2: LITERATURE REVIEW

2.0	Introduction	5
2.1	General Vibration	7
2.1.1	Vehicle Vibration	8
2.1.1.1	Chassis Vibration	10
2.2	Electric Vehicle	11
2.3	Vibration Measurement	13
2.3.1	Transducer	14
2.4	Vibration Analysis	15
2.4.1	Data Analysis (FFT)	16
2.5	Previous Research	19

CHAPTER 3: METHODOLOGY

3.0	Introduction	23
-----	--------------	----

3.1	Selection of Equipment and Transducer	23
3.1.1	Equipment	23
3.1.2	Transducers	24
3.1.3	Software	24
3.2	Sensor Tapping Location	24
3.3	Vibration Data Collection	27
3.4	Data Acquisition and Processing (MATlab)	28

CHAPTER 4: RESULT AND DISCUSSION

4.0	Introduction	31
4.1	Case Study	31
4.1.1	Signal Verification	32
4.1.1.1	Raw Signal	32
4.1.1.2	Filtering	36
4.2	Result and Discussion	39
4.2.1	Fast Fourier Transform (FFT)	39
4.2.1.1	FFT at Point A	40
4.2.1.2	FFT at Point B and C	41
4.2.2	Effect of Bushings	42
4.2.3	System Monitoring	44
4.2.3.1	Component Monitoring	44
4.3	Limitation in These Studies	46

CHAPTER 5: CONCLUSIONS

5.0	Introduction	48
5.1	Summary of Studies	48
5.2	Recommendation for Future Studies	49

REFERENCES	50
-------------------	----

LIST OF FIGURES

2.1	Basic Electric System Powertrain	12
2.2	FFT Power Spectrum	17
3.1	Toyota Prius	23
3.2	Point A Tapping Position	24
3.3	Point B Tapping Position	25
3.4	Sensor Position at Point B	25
3.5	Point C Tapping Position	26
3.6	Portable Signal Analyzer Equipment	27
4.1	Point A at 1000RPM	32
4.2	Point A at 1500RPM	32
4.3	Point A at 2500RPM	33
4.4	Point B at 2500RPM	34
4.5	Point C at 2500RPM	34
4.6	Engine at 2500RPM	35
4.7	Point A at 1000RPM after filtering	36
4.8	Point A at 1500RPM after filtering	36
4.9	Point A at 2500RPM after filtering	37
4.10	Point B at 2500RPM after filtering	37
4.11	Point C at 2500RPM after filtering	38
4.12	FFT of Point A at 1000RPM	39
4.13	FFT of Point A at 1500RPM	39
4.14	FFT of Point A at 2500RPM	40
4.15	FFT of Point B at 2500RPM	40
4.16	FFT of Point C at 2500RPM	41
4.17	FFT of Engine at 2500RPM	42
4.18	FFT of Point A at 2500RPM	42
4.19	FFT at Point A	44

4.20	FFT at Point B	44
4.21	FFT at Point C	45

CHAPTER 1

INTRODUCTION

1.0 Introduction

Automotive chassis is a frame which various mechanical parts such as engine, tires, axle assemblies, brakes and steering are bolted together. It is considered to be the most significant component of an automobile. It is the crucial element that gives strength and stability to the vehicle under various condition. The frames provide strength and flexibility to the automobile. It is considered the backbone of any structure including automobile which supports any parts or components in place. In this chapter, we will explain the chassis of an automobile that is involved in the final year project.

1.1 Background

There were a lot of improvement that made by the engineers in advancing the technology of the chassis system in keeping an automobile rigid, stiff and unbending. They also improvise on ensuring low noise level, vibration and harshness throughout the automobile. There are multiple chassis types that exist from the early year of land vehicles.

Ladder chassis is considered to be the one of the oldest forms of automotive chassis that is still used by most of the SUV's till today. The ladder frame is the simplest and oldest of all design. It consists merely of two symmetrical rails, or beams, and cross member connecting them. Originally seen on almost all vehicles, the ladder frame was gradually phased out on cars around the 1940s in favours of perimeter frames and now seen mainly on trucks. This design offers good beam resistance because of its continuous rails from front to rear, but poor resistance to torsion or

warping is simple, perpendicular cross member are used. Also, the vehicle's overall height will be higher due to the floor pan sitting above the frame instead of inside it.

Perimeter frame, is similar to ladder frame but middle section of the frame rails sits outboard of the front and rear rails just behind the rocker panels or sill panels. This was done to allow for a lower floor pan and therefor lower overall vehicle in passenger cars. In addition of a lowered roof, the perimeter frame allows for more comfortable lower seating positions and offers better safety in event of side impact but it isn't used in all vehicle due to lack of stiffness.

Unibody is the most common design that were used in today's vehicle. If a unibody is damaged in an accident, getting bent or warped, in effect to its frame too, and the vehicle not drivable. If the body of a body-on-frame vehicle is similarly damaged, it might be torn in places from the frame, which may be straight, in which case the vehicle is simpler and cheaper to repair.

The main function for the development of chassis is to support the vehicles mechanical components and body as it acts as the skeletal for a vehicle. It also deals with static and dynamic loads which is the weight of the body, passengers, and cargo loads, vertical and torsional twisting, transverse lateral forces caused by outside natural outside forces, torque from engine and transmission and sudden impacts from the event of collisions.

1.2 Problem Statement

Nowadays, the resulting vibration in the chassis or frame is a problem that is the main topic in this study. Research conducted to solve the problem of vibration on the chassis has been made and these issues are too difficult to overcome as there could be many factors that could be causing it. When passengers and driver is in the car that is mobile, they could feel vibration from the cabin, seat and floor as chassis is connected to all the parts in a car.

One of the factors that involved could be from the design of the vehicle and type of chassis itself. As we know, the chassis is the frame where all the components of the car are bolted on including the suspension and engine. The suspension is

connected to the tyre that is directly in contact to the road that could be uneven and cause the car to shake or vibrate,

Engine also plays a major role in causing the care to vibrate as engine normally produce vibration that is natural to its characteristic due to its internal moving components whether the assembly or accessories. It also because of the engine imbalance, firing frequency, engine mounts and engine accessories.

All of these vibrations may seem normal on most cars but it could tell us that something is wrong with the vehicle. An early detection of the problem could save a lot of money, energy and time.

To investigate the what is the source of the problem in an automobile which is in this case a Toyota Prius, a hybrid car, the vibration is analysed using specific software such as MATLAB software implementing the technique of Fast Fourier Transform (FFT) with equipment of measuring vibration or motion, accelerometer. The result then will be analysed.

1.3 Objectives

Objective is the goal or target that is needed to be achieved at the end of a project research or study. Every project must have an objective to keep the project in the right track and define it more clearly. This signal analysis of vibration for chassis of hybrid vehicle (HV), has 3 objectives that need to be achieved. The objectives are as follows.

- i) To study effect of engine mounting bushings.
- ii) To monitor the condition of the system.
- iii) To use Fast Fourier Transform method in analysing signals.

For the first objective, this project will detect the problems that is related to the vibration. And from the result that we get from this project could analyse the effect of bushings in filtering vibration from being transmitted to the car cabin.

In the second objective, this method of analysing the chassis frame of a vehicle could monitor the condition besides of detecting faults. Early detection of problems could be very useful to prevent sudden breakdown of the system.

The final objective is to use Fast Fourier Transform (FFT) to analyse raw signal to a more suitable and understandable format.

1.4 Scope

This project is a chassis vibration analysis of a hybrid vehicle (HV) using MATLAB software. The scope of this project is to cover the case of study through the literature reviews on hybrid car chassis for automotive vehicle.

This project also studies the functions of FFT in vibration signal analysing.

- i) This project focuses on the electric car chassis.
- ii) Applying model analysis on the hybrid car chassis.
- iii) Studying FFT.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

A literature review is a text that contains current knowledge including substantive findings, as well as theoretical and methodological contribution in a particular topic. This is considered secondary sources that does not report new or original experimental work. Most reviews are found in academic journal, and are not to be confused with book reviews that may also appear in the same publication. This is the basis step for a research in almost every academic field. (Wikipedia,2016)

Producing this literature review are a part of graduate and post-graduate student work that follows by the preparation of a thesis, dissertation, or a journal article. Literature review are also common in research proposal which is the document that is approved before a student formally begins a dissertation or thesis for a project. (Wikipedia,2016)

Common literature review could be 15 to 30 pages or longer. This process of writing a literature review requires different kinds of activities and thinking. It is linked to the cognitive way of thinking which is remembering, understanding, applying, analysing, evaluating, and creating. (Wikipedia,2016)

For a person doing a literature review this included tasks such as recognition, retrieval and recollection of the relevant literature. In this stage, relevant books, articles, monographs, dissertation are identified and read. The second category, understanding occurs as scholar comprehends the material they have collected and read which is the critical step because no one can write clearly about something they do not understand. (Wikipedia,2016)

Comprehension is improved by taking notes carefully. The third category is the scholar is able to make connections between literature and the research project. The literature review begins to inform the research question, and methodological approaches. (Wikipedia,2016)

The fourth category, analyse, scholars are able to separate material into parts and figuring out on how to fit the parts together. The analysis allows to develop frameworks for analysis and the ability to see big picture and acknowledge the details from literature fit into the research or project. Analysis helps and facilitate the development of an outline. (Wikipedia,2016)

The fifth category, scholars are able to see through the weakness and strength of a theories, arguments, methodology, and findings of the literature that have been collected and read. When engaged in creating which is the final category, creativity will flow in the process of doing literature review which can be drawing new and original insight from the literature. Fresh and original research question, identify a heretofore, unknown gap in literature or by making surprising connections. (Wikipedia,2016)

By understanding ways of thinking connect to task, a scholar able to self-reflect and bring metacognition in process of reviewing. (Wikipedia,2016)

The step in writing a literature review is by research approaching which is plans and procedures for research that spans from broad assumption to detailed method of data collection, analysis, and interpretation. The plan involves decisions, and they are not to be taken in order they made sense and order of the presentation. Overall decision involves which approach should be used to study a topic. (Creswell, John W. 2013)

Informing the decision should be philosophical assumption the researcher brings to the study; steps of inquiry which called research designs and specific research methods of data collection, analysis, and interpretation. Selection of a research approach is also based on the nature of the research problem or issue being addressed by researcher's personal experiences and audience for the study. (Creswell John W. 2013)

There are 3 types of approach which is qualitative, quantitative and mixed method. Qualitative is for exploring and understanding the meaning individuals or groups ascribe to social or human problem. This form of enquiry supports a way of looking at research that honours inductive style, a focus on individual meaning, and the importance of rendering the complexity of a situation that results in flexible structure of the final written report.(Creswell 2014)

Quantitative is an approach for testing objective theories by examining relationship among variables. In this form of enquiry assumption can be obtained about

testing theories deductively, building protection against bias, control for alternative explanation and able to generalize and replicate findings that results in final written report that has set structure consisting introduction, literature and theory, methods, results and discussion. (Creswell 2014)

Mixed method involves collecting both quantitative and qualitative data, integrating the two form of data and using distinct design that involve philosophical assumption and theoretical frameworks. The main assumption of this form is that the combination of qualitative and quantitative approaches provides a more complete understanding of research problem than either approach alone.

2.1 General Vibration

Vibration word comes from Latin vibrationem that means shaking or brandishing. It is a mechanical phenomenon where oscillation occurs about an equilibrium point that may be periodic or random. (Wikipedia,2016)

It is evident everywhere and in many cases greatly affects the nature of engineering designs. Vibrational properties of engineering devices often limiting their performance. When harmful, it should be avoided but It also could be useful. Vibration is prevalent in biological systems and is in fact at the source of communication.(Inman 2008)

The term vibration in engineering describes the repetitive motion that can be measured and observed in a structure, while unwanted vibration would cause fatigue or degrade performance of the structure. Even it could minimise the effect of vibration, it is unavoidable in a structure.(LDS 2003)

Physical explanation of the phenomena of vibration concerns the interplay between potential energy and kinetic energy. A system that vibrates must have component that stores potential energy and releases it as kinetic energy in form of vibration motion of a mass. The movement of the mass than gives up kinetic energy to the potential-energy storing component.(Inman 2008)

Vibratory motions in machines are frequent concern in engineering practices. Such motion sometimes could be desirable hence it is usually questionable.(Tong 1963)

Although the intensity of the vibration can be felt, is a physical movement or motion which its frequency and amplitude cannot be measured by sight or touch. A method must be applied to convert vibration into usable product that can be measured and analyzed related to electronics, mechanics and chemical physics.(Taylor 2003)

There are 4 types of common vibration which is free vibration, forced vibration, sinusoidal vibration and rotating imbalance. Free vibration is the natural response of a structure to some impact or displacement and the response is completely determined by the properties of a structure. The vibration characteristic can be understood by examining the structure mechanical properties.(Instruments 2003)

Forced vibration is the response of a structure to a continuous forcing function that causes the structure to vibrate at frequency of excitation. There is deterministic relationship between the amplitude of corresponding vibration level and forcing function but it also dictated by the structure's characteristic.(Instruments 2003)

Sinusoidal vibration is created when the structure is excited by a forcing function that is a pure tone with a single frequency. It is not a common type of vibration in nature but it provides excellent engineering tool that enables to understand complex vibration by breaking them down into simple one-tone vibrations.(LDS 2003)

Rotating imbalance is a common source of vibration that occurs by a rotation of an unbalanced machine part that can cause the whole machine to vibrate. The imbalance generates forcing function that could affect the structure. It is usually harmful to the machine and unwanted. The proper way to minimize the vibration is properly balancing the machine rotating parts.(Instruments 2003)

2.1.1 Vehicle Vibration

On owning an automobile or vehicle, it is a very common and bothersome to develop vibration problem. Low frequency vibration occurs either as a cause in adjacent environment or within the vehicle itself. Excessive vibrations could interfere with human activity and cause mechanical or electrical on-board equipment malfunction.(Stein et al. 2007)

Vertical Shake is severe vertical vibration of the body, seats and steering wheel. A trembling engine hood or rearview mirror also can be vertical shake symptom. Lateral shake is side-to-side vibration of body, seats, and steering wheel. A trembling vibration in the driver's waist or hips may be a symptom of lateral shake.

Road roughness and tires are the major contributor to vehicle vibration that occurs during driving. The impact force from road surfaces transmits to the tires causing them to vibrate that then transmitted to the suspension and body.(Program 2005)

On road vehicle, the movement on an uneven pavement are the main cause of vibration in automobile that transfers to passengers. The level of road surface directly affects the vibration of a land vehicle vibration intensity.(Lakušić et al. 2011)

Vibration or chatter also formed in automobile because of the slip phase of the clutch in the drive train of an automobile and are generated in the clutch area that specifically named chatter. It is when periodic torque change is generated in slipping clutch with natural frequency between 8 and 12 Hz with engine speed from 480 to 720 rpm. (Albert Albers, Daniel Herbst)

The drive wheels converting rotating vibration of drive train to longitudinal vibration of the vehicle. It is expressed as a vibration in the longitudinal direction of vehicle and transferred via the operating elements and driver's seat that cause unpleasant vibration to driver.(Barber 2005)

Resonance also contribute to a vehicle vibration. As the tire speed increases along with the vehicle speed, the disturbance created by the unbalanced tire increases in frequency. Eventually, the frequency of the unbalanced tire would intersect with the natural frequency of the suspension, causing the suspension to vibrate.(Program 2005)

Brake squealing is also a common vibration and noise problems in vehicle. It occurs when friction is created between braking components during braking event. Worn or damaged brake components results in vibration that leads to squealing. Vibrating or squealing brake are also caused by non-uniform thickness of brake disc or drum and damage or contamination of friction surfaces.(Program 2005)

Vibration also results from the engine of a vehicle. Engine vibration are caused by component driven by the engine that may be part of the engine assembly or an engine accessory. Many noise and vibration are related to the engine systems as the engine produce natural vibration upon operation. Vibration of the engine is generally caused by first and second-order engine imbalance, engine firing frequency, engine mounts and engine accessories.(Program 2005)

First-order engine imbalance is created when any component that rotates at crankshaft speed out-of-balance or has excessive runout. It could be the harmonic balancer, flywheel or torque converter imbalance and cylinder-to-cylinder mass differences. Second-order engine imbalance is caused by the up-and-down motion of pistons. The reversal of mass and motion creates natural vibration.(Program 2005)

The component that isolates vibration from the engine to passenger compartment or cabin are engine mounts. These parts are extremely important in preventing noise and vibration produced by the engine. Torque reaction force of engine acts directly on the transmission causing engine mounts subjected to a large force. The mounts must be soft to minimize the inherent engine vibration and noise during all speed operation.(Program 2005)

2.1.1.1 Chassis Vibration

Chassis consist of internal vehicle frame that act as a support to a manmade object in its construction. But in this literature review, we focus on vehicle chassis. A chassis in an automobile is the underpart of a motor vehicle, consisting the frame, where the body is mounted.

As a car travels along the road, the car chassis is excited by dynamic forces induced by the road roughness, engine, transmission and more. Under such various dynamic excitations, the chassis of the car tends to vibrate.(Renuke 2012)

The general vehicle vibrational characteristic of a vehicle is related to both its stiffness and mass distribution. The frequencies of the global bending and torsional vibration modes are commonly used as benchmarks for vehicle structural performance. Bending and torsion stiffness influence the vibrational behavior of the structure, particularly its first natural frequency.(Renuke 2012)

There are two types of vibration which is global and local vibration. The global vibration means that the whole chassis structure is vibrating while the local vibration means the vibration is localized and only part of the car chassis is vibrating.(Renuke 2012)

Low frequency vibration occurs in ground transportation either as a cause in adjacent environment or within the vehicle itself that can vary in frequency content from well below 1 Hz and up to 20 Hz. Excessive vibration could interfere with human activity and may cause malfunction of mechanical and electronic equipment of the vehicle.(Stein et al. 2007)

2.2 Electric Vehicle

Electrical vehicle eliminates the use of fuel tank and internal combustion engine meaning that it does not consume fossil fuel. It consists of battery and electric motor that replace the conventional drive train but may share some component from conventional system such as transmission and gear box. Electric motor serves as the power source or the heart of the car that makes it move.(United Nations Environment Programme 2009)

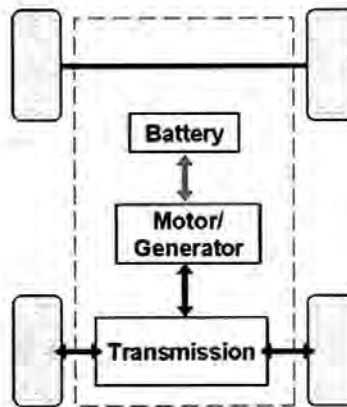


Figure 2.1: *Basic Electric System Powertrain* (Berry & Khusid 2009)

EV started to develop in 1827. Then first introduced to public on the mid-19th when electricity was among the preferred methods for motor vehicle propulsion that provide comfort and ease of operation that were not achievable by internal combustion engine at that time. (Wikipedia, 2016)

This type of vehicle is one of the earliest automobile before the powerful internal combustion engine in the early 1900s and out-sold gasoline-powered engine. It then outrun by the conventional engine as gasoline became easier to obtain and cheaper to operate with the invention of electric starter. (Wikipedia, 2016)

Electric vehicle or in short EV, consist of large battery pack and recharged with energy from a conventional wall plug. Beside from plugging to the wall, HV also can regenerate electricity that can be stored into the battery pack by recuperating braking energy that were lost in the event of braking the vehicle or when moving downhill that commonly known as regenerative braking.(United Nations Environment Programme 2009)

2.3 Vibration Measurement

The use of vibration measurement is to monitor rotating machinery in providing warning of gradually approached or suddenly encountered excessively high vibration intensity that could lead to damage to the machinery. The trending on machinery vibration over an extended period of time can potentially provide early warning of problem related to the machinery.(Fallis 2013)

Rotating machines produce vibrations that are a function of the machine dynamics that shows the alignment and balance of the rotating parts. Measuring amplitude of vibration at certain frequencies could provide information on the accuracy of shaft alignment and balance, condition of bearing and gears, effect on machine due to resonance from housing, piping and other structures.(Fallis 2013)

There are three main parameters that were measured to evaluate the vibration characteristics of any dynamic system as displacement, velocity and acceleration. Peak-to-peak distance is measured from upper limit to lower limit. Velocity of a vibrating object is constantly changing as its movement periodically stops and reverse its direction of travel when its velocity at peak lower and upper limit is zero.(Fallis 2013)

Displacement measurement of vibration are important in low frequency vibration on machines that consist brittle component as the stress that developed could be sufficient to snap the component. Acceleration are also important as the other two parameters as it directly measure force that could lead to improper lubrication in journal bearings and result in failure.(Fallis 2013)

By the advanced technology that were developed today, the measurement of vibration becomes much easier as it uses digital from analog measurement unit that can easily be analyzed. The three equipment that commonly used to measure the parameters of vibration is accelerometer, velocity transducer and displacement transducer which convert the analog signal from the vibrating object from analog to digital form.(Fallis 2013)