DEVELOPMENT OF DYNAMIC RESPONSE ANALYSIS FOR FLEXIBLE LIGHTWEIGHT VEHICLE CHASSIS

by

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A thesis submitted in fulfillment of the requirements for the degree of Master of Science (Manufacturing Engineering)

School of Manufacturing
UNIVERSITI MALAYSIA PERLIS

2018

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ACKNOWLEDGMENT

It has been a period of intense learning, not only in the scientific arena, but also on a personal level. This is not overreacting to acknowledge every role that involved in completing this research. First of all, thanks to ALLAH that granted me to finish the study. Then acknowledgements go to my precious people which are my family who always give support and encourage to increase knowledge and to be a better person.

Besides, special thanks to my respectful main supervisor En. Jamali bin Md Sah, who bring out the research study and give the opportunity to be his student with guidance through the research work. Same goes to my co-supervisor Dr Suhaila Hussain, that willing to share the knowledge and guidance for the correct path of the research study. There are also my gratitude to the place of my study which is the Universiti Malaysia Perlis precisely School of Manufacturing and the Library of Uni. Malaysia Perlis that provided the accommodation with convenience place to study, extensive machinery and the computers with CAE software.

Furthermore, there is also a good chance that I was able to attend the training course of CAE software from Dassault Consultant that can assists and guide to apply CAE software in my study. Technician also is very cooperative in assist to use lab and machinery to execute the experiment procedure. Specific thanks also to my dear friend, Muhamad Hafiz Bin Brahim that is willing to lend help during go-kart experiment conducted. Other than that, many thanks to all my beloved friends who also sharing joy and lighten the research hardship and keeps me enthusiastic pursued the research without regret. Also thanks to who is involved directly and indirectly although not specifically mentioned but the cooperation is really appreciated.

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LIST OF ABBREVIATIONS

CAD	Computer Aided Design
CAE	Computer Aided Engineering
CMM	Coordinate Measuring Machine
CORM	Component of Relative Motion
DAQ	Data Acquisition
DOF	Degree of Freedom
DOSH	Department of Occupational Safety and Health
FEM	Finite Element Method
GPS	Global Positioning System
ISO	International Organization for Standardization
MBD	Multi Body Dynamic
NI	National Instrument
ODB	Output Data Base
PC	Personal Computer
RI	Ride Index
RMS	Root Mean Square
TLV	Threshold Limit Vibration
VDV	Vibration Dose Value

LIST OF SYMBOLS

E	Young Modulus
ρ	density
m,M	mass
v	volume
k,K	stiffness
C	damping
t	time
$\ddot{x}$	acceleration on x-axis
$\dot{x}$	velocity on x-axis
x	displacement on x-axis
$\ddot{y}$	acceleration on y-axis
$\ddot{\psi}$	yaw direction
g	gravity force
$\sum F_x$	Total of Force on x-axis
$\sum F_y$	Total of Force on y-axis
$\sum M_z$	Total of Moment on z-axis
F_{z1}	Force on vertical axis for right front tires
F_{z2}	Force on vertical axis for left front tires
F_{z3}	Force on vertical axis for right front tires
F_{z4}	Force on vertical axis for left front tires
Δu	changes of acceleration
Δv	changes of velocity
Δt	Time increment
i	initial condition
j	final condition
x	Translational on x-axis
y	Translational on y-axis

z	Translational on z-axis
Rx	Rotational on x-axis
Ry	Rotational on y-axis
Rz	Rotational on z-axis
${}^{t}\ddot{U}$	acceleration vector of finite element due to time
${}^{t}\dot{U}$	velocity vector of finite elemet due to time
U	displacement vector of finite element due to time

PEMBANGUNAN ANALISIS TINDAK BALAS DINAMIK UNTUK CASIS KENDERAAN RINGAN YANG FLEKSIBEL

ABSTRAK

Perkembangan dalam reka bentuk kenderaan adalah semakin membangun. Banyak ciptaan baru muncul untuk membina kenderaan yang lebih baik. Terdapat percubaan untuk menggantikan keluli dengan bahan-bahan yang lebih ringan untuk mengurangkan berat kenderaan. Walau bagaimanapun, proses ini menghadapi kesukaran untuk menangani sifat-sifat bahan untuk mendapatkan kesesuaian dengan prestasi kenderaan. Cabaran penggunaan bahan ringan adalah isu getaran pada struktur casis dan kos yang mahal untuk membina prototaip fizikal. Oleh itu, kajian ini adalah untuk mengkaji isu getaran dalam memperbaiki pembangunan reka bentuk casis go-kart. Kaedah yang digunakan adalah simulasi dinamik berbilang badan dengan menggunakan perisian Kejuruteraan Dibantu Komputer. Model simulasi ini menggunakan model fizikal sebenar sebagai panduan untuk membina model simulasi go-kart. Simulasi ini direka bentuk sebagai model kenderaan go-kart yang bergerak di atas permukaan jalan yang berbonggol. Permukaan jalan berbonggol mewakili pengujaan getaran ke atas model go-kart. Model go-kart ini dibina sebagai model dinamik pelbagai badan iaitu badan casis yang boleh berubah bentuk dan dihubungkan dengan tayar yang boleh berubah bentuk. Untuk membina pergerakan go kart yang betul, tahap kebebasan pergerakan diberikan kepada bahagian-bahagian yang telah disambungkan dengan menggunakan had sempadan dan kekangan. Interaksi sentuh juga direka antara tayar dan benjolan jalan. Hasil dapatan model simulasi ialah hasil pecutan yang digunakan untuk mengesahkan keputusan simulasi dengan hasil pecutan daripada eksperimen. Fenomena getaran untuk go-kart casis diuji melalui eksperimen yang dijalankan. Eksperimen ini dilaksanakan mengikut model simulasi. Keputusan eksperimen yang diperolehi, dianalisis melalui alat Instrumen Kebangsaan (NI). Getaran enjin ditapis dari hasil eksperimen untuk mendapatkan hasil korelasi dengan simulasi. Dari hasil pengesahan dengan eksperimen, model simulasi diperolehi sebanyak 13% dari peratusan ralat. Ini menunjukkan kebolehpercayaan model simulasi dalam perisian komputer. Model simulasi ini diaplikasi untuk casis yang lebih ringan iaitu aluminium casis untuk mengkaji tingkah laku struktur dan aplikasi aluminium dalam membina kenderaan go kart. Keputusan yang ditunjukkan menunjukkan bahawa struktur keluli mempunyai getaran yang lebih tinggi berbanding aluminium, namun dari keputusan Von Mises Stress, menyatakan bahawa struktur aluminium lebih mudah untuk berubah bentuk daripada struktur keluli. Melalui kaedah model simulasi analisis, penggunaan casis aluminium boleh dilaksanakan dalam pembangunan kenderaan ringan. Parameter yang mempengaruhi mudah dimanipulasi melalui perisian Kejuruteraan Dibantu Komputer dan menawarkan manfaat dalam pengurangan kos dan masa pengeluaran daripada menggunakan kaedah konvensional. Teknik analisis simulasi ini adalah amalan yang bagus untuk membangunkan produk yang baik.

DEVELOPMENT OF DYNAMIC RESPONSE ANALYSIS FOR FLEXIBLE LIGHTWEIGHT VEHICLE CHASSIS

ABSTRACT

The development in vehicle design is on-going growth. Many new inventions appeared to produce a better vehicle. There is also an effort to replace steel with a lighter weight of material such as aluminium in order to reduce weight of vehicle. However, this process facing difficulty when dealing with the properties of the material and its compatibility to the vehicle performance. The challenge of the light material usage is the vibrational issue on the chassis structure and expensive cost for physical prototyping models. Hence, this research is to study the vibrational issue in improving the development of go-kart chassis. The method applied is the simulation of multi-body dynamic using Computer Aided Engineering (CAE) software. The computational model is based on the real physical model. Simulation model is designed as a go-kart vehicle running on the road bump surface. The road bump surface represents the excitation of the vibration to the go-kart model. This go-kart model is developed as a multi-body dynamic model which is the deformable chassis body linked with the deformable tires. To develop the proper movement of the go-kart, the degree of freedom is assigned to the joined parts using boundary condition and constraint. The interaction contact is also developed between the tire and the road bump. Output of the simulation model is acceleration parameters that being used to validate the simulation result with acceleration gain from experiment. The real vibration phenomena of the chassis go-kart are tested through the experiment. The experiment is set up according to the simulation model. The result from the experiment is obtained and analyzed through National Instrument (NI) tools. Engine vibration is filtered from experimental result to get the correlation result with simulation. From the verification result through experiment, the simulation model is obtained 13% of the percentage error. This classified the reliability of the simulation model in the CAE software. This validated simulation model is applied for lightweight chassis which is aluminium to study the structure behavior and application of aluminum in develop chassis vehicle. The plotted result shown that the steel structure has higher vibration than aluminum, however from Von Mises Stress result, expressed that aluminum structure is easier to deform rather than steel structure. Through the analysis simulation model, the application of aluminum chassis is feasible in the application of lightweight vehicle chassis. The affect parameters are easily manipulated through CAE software and offer some benefits such as cost reduction and minimize production time rather than using conventional method. This simulation analysis technique is the efficient practice to produce the lightweight vehicle.

CHAPTER 1: INTRODUCTION

1.1 Background Study

Automobile industry is one industry that growing fast in order to satisfy consumer need and aligned with the rapid pace of the challenge in the automobile manufactures. Design of vehicle needs to meet the function criterion without neglecting the quality that users always emphasized such as speed, safety and comfort. In this modern time, fuel economy is been included as objective of the vehicle design. Automakers have facing a challenge in reducing fuel consumption for the vehicle manufactured. The main point in saving fuel consumption of a vehicle is weight reduction. Commonly, without affecting the function of the vehicle, weight of vehicle can be reduced by scaling down the size because logically, when the larger vehicle the more power needs in accelerating the vehicle. Designer have facing challenge in reducing fuel consumption for the vehicle invented when the conventional method reach the limit with the appearance of new engines technology and sophisticated car accessory features have caused the weight increasing of the vehicle. This situation has been discussed in USA Today magazines through the article by Woodyard (2007). Below is the average size for car and curb weight which is defined the weight of vehicle with all fluids and components without user and loading.

Table 1.1: Average dimensions for vehicles in various segments (Woodyard, 2007)

Year	**Length (m)**	**Width (m)**	**Height (m)**	**Curb Weight (kg)**
Sedan Compact				
1990	4.46024	1.68656	1.36652	1176.75
2007	4.50088	1.74752	1.45796	1351.43
Sedan Midsize				
1990	4.86918	1.7907	1.39446	1457.30
2007	4.826	1.81356	1.45796	1581.76
Sedan Large				
1990	5.31876	1.88214	1.42494	1744.92
2007	5.2324	1.90754	1.48844	1980.15
SUV Compact				
1992	4.4704	1.6891	1.67894	1834.78
2007	4.37642	1.80086	1.73228	1574.06
SUV Midsize				
1995	4.5466	1.80086	1.64338	1666.50
2007	4.75488	1.87452	1.76784	1931.94
SUV Large				
1999	5.5753	1.94818	1.84912	2378.82
2007	5.2832	1.98628	1.90754	2454.48

According to the issue, here comes new possible approach in the making of automobile body which is by using alternative lightweight material instead of existing carbon steel. For a long time ago, steel was the only option for vehicle structure. However, the design of Hyper car which is emphasizing the ultra-lightweight design have been trigger-up by Lovins & Cramer (2004). This lightweight vehicle is the concepts that have attracted great attention among the auto industry leaders to put huge effort and funding in establish research and development activities. Lightweight vehicle structures are created in accordance with the development of new engine technology. The Hypercar project came out with new design of car, using other substantial material other than using carbon steel. Aluminum is one of the selected materials that precede other materials in meeting the requirements of light vehicle design.

Although aluminum is expensive compared with steel, in the last few years, researchers in automobile industry have shown some interest in studying the possibility of substituting aluminum rather using steel in car bodies to develop lightweight vehicle (Association, 2006). Similar to its metallic family members, aluminium can be formed by using almost all of the technique applied in the making out of vehicle structure using steel such as stamping and extrusion. It is not exaggeration to say that aluminium can be used to replace steel. It is worth it using aluminum in develop lightweight vehicle, when fuel consumption can be reduced and met performance requirement. Any revolutionary in the aluminium application of lightweight vehicle is the breakthrough of the new future in automobile industry. In these recent years, many improvements and innovation of aluminium usage that have possibility to meet the economic and ecological demand, for example by adding a simulation process using CAE tools in the making of lightweight automobile.

The implementation of replacement part by part using aluminium in the vehicle structure is difficult to achieve due to large number of parts. It is necessary to make critical redesign of the automobile body to optimal the use of aluminium. In practice, to deal with the complexity relationship between the material properties, strength, stiffness and weight of a part, CAE tools can be applied to virtualize the design concept of aluminium structure with finite element analysis. Generally, in conducting finite element analysis through CAE software, there are sequence stages which are, pre- processing, processing analysis, and post-processing. To begin the analysis, there have to be an input which is pre-processing. Through this phase, the geometry is modeled with discrete element and assigned with initial condition, loading, physical behaviour of materials and other inputs that describe the problems. The solution phase determines the solver that solves the algebraic function. Meanwhile, post-processing phase is visualized the output of the analysis.

The emergences of CAE analysis method in the automobile industry have encouraged automakers to study the usage of aluminium for lightweight vehicle, where there is complexity of mathematical modeling and high cost predicted in conducting experimental analysis. The application of CAE software can model the condition of lightweight vehicle to almost exactly with the real world. The result of the simulation is useful for reducing lead time in mass production. The process of product testing can be shortened with the aid of simulation result. CAE software is offering finite element analysis and presenting multi-physic capabilities of the structure. Most of the researchers have been applied CAE tools in their studies over the last few years, for example Mirrone et al.(2010) was using ADAMS to study stiffness of structure , Gouqing et al. (2012) was using CAE

ANSYS in conducting Finite Element on chassis, Muzzupappa et al. (2006) integrate the virtual modelling analysis from CAD and from FEM into multi-body analysis to validate the result between experimental result and virtual result through ADAMS software. Another current CAE tools is Abaqus software. From time being, Abaqus software has gone through many improvements that make this software have become the efficient software to model static and dynamic problem. The ability of Abaqus is to do variety of analysis such as failure analysis, facture mechanics, heat transfer, and vibration analysis under extensive material definition. Sophisticated software like Abaqus, is possible to investigate dynamic behaviour of mechanical systems such as vibration phenomena of the lightweight vehicles.

The success of lightweight vehicle design is included the good feeling and comfort of the user during riding. One of the criteria that have to be considered in satisfying those requirements is vibration effect. A vibration phenomenon is recognized as periodic motion of an elastic body in opposite direction from the position of the equilibrium. The vibration of vehicle is caused from dynamic force that initiated by road irregularities, engine, load, and others aspect that is possible. Vibration transmission from vehicle to human body which not been handle properly can affect long-terms health to user. Vibration effect on human body can be seen slowly, begin with feel pain and if continue vibration exposure, pain may develop to injury or diseases. Symptoms that most people faced during a long car trip are such as fatigue, insomnia, stomach problems, headache and body shakiness shortly after experiencing the vibration. There are some guidelines have been gazette by Department of Occupational Safety and Health of Malaysia(Department of Occupational

Safety and Health, 2003). The Threshold Limit Vibration (TLV) in Table 1.2 is for whole-body vibration following ISO 2631. Vibration exposure is measured by acceleration and frequency level. The durations also determine the limit of the vibration exposure.

Table 1.2 Numerical value in longitudinal a_z (foot-to-head) direction following ISO standard (Department of Occupational Safety and Health, 2003)

Frequency	**Acceleration (m/s^2)**								
Hz	24h	16h	8h	4h	2.5h	1h	25min	16min	1min
1.00	0.28	0.383	0.63	1.06	1.40	2.36	3.55	4.25	5.60
1.25	0.25	0.338	0.56	0.95	1.26	2.12	3.15	3.75	5.00
1.60	0.22	0.302	0.50	0.85	1.12	1.90	2.80	3.35	4.50
2.00	0.22	0.27	0.45	0.75	1.00	1.70	2.50	3.00	4.00
2.50	0.18	0.23	0.40	0.67	0.90	1.50	2.24	2.65	3.55
3.15	0.16	0.212	0.355	0.60	0.80	1.32	2.00	2.35	3.15
4.00	0.14	0.192	0.315	0.53	0.71	1.18	1.80	2.12	2.80
5.00	0.14	0.192	0.315	0.53	0.71	1.18	1.80	2.12	2.80
6.30	0.14	0.192	0.315	0.53	0.71	1.18	1.80	2.12	2.80
8.00	0.14	0.192	0.315	0.53	0.71	1.18	1.80	2.12	2.80
10.00	0.18	0.239	0.40	0.67	0.90	1.50	2.24	2.65	3.55
12.50	0.22	0.302	0.50	0.85	1.12	1.90	2.80	3.35	4.50
16.00	0.28	0.383	0.63	1.06	1.40	2.36	3.55	4.25	5.60
20.00	0.36	0.477	0.80	1.32	1.80	3.00	4.50	5.30	7.10
25.00	0.45	0.605	1.00	1.70	2.24	3.75	5.60	6.70	9.00
31.50	0.56	0.765	1.25	2.12	2.80	4.75	7.10	8.50	11.20
40.00	0.71	0.955	1.60	2.65	3.55	6.00	9.00	10.60	14.00
50.00	0.90	1.19	2.00	3.35	4.50	7.50	11.20	13.20	18.00
63.00	1.12	1.53	2.50	4.20	5.60	9.50	14.00	17.00	22.40
80.00	1.40	1.91	3.15	5.30	7.10	11.80	18.00	21.20	28.00

The international standards guidelines can be used as a reference to know the limit of vibration exposure to human body. Higher vibration cannot be exposed to human body for long period. According to this condition for people that involved with lightweight vehicle will be high contingency in suffering diseases caused by vibration. This can be seen through go-kart sport which is categorized as lightweight vehicle. In go-kart sport, it is very particular in protecting driver safety by reducing vibration transmitted to driver body.

For the passenger vehicle which is normally attached with suspension systems, the effective way to control vibration is by controlling vehicle suspension (Lin, Padovan, & Lu, 1992) . However, for lightweight vehicle with the absence of suspensions systems such as go-kart, the performances of the vehicle are strongly influenced by the structural characteristics of the chassis. As one of the critical component, chassis designs need to meet its function to carry vehicle loading such as, engine and driver weight, braking and cornering force. Along with the lightweight vehicle development, chassis has undergone many improvements in realization of lightweight vehicle. Transmission of vibration can be reduced by incorporating component between user and source of vibration (Donati, 2002). Chassis as the major component can be manipulated to achieve the goals of weight reduction in vehicle design. Chassis structures without suspension can produce high levels of vibration from low level disturbance sources. It is happen when the frequency of disturbance component are close to one of the natural frequencies of the systems. This means that, the component with good design and low vibration might produce other problems when assembled with other components. In order to avoid these problems at the design stage it is necessary to model the system accurately and analyse its response to anticipated disturbances.

For this reason, flexible multi-body dynamic method have been studied to find the solution of the best design for chassis that can achieved possibility of inventing an affordable lightweight vehicle. Kane et al. as cited by Ryu & Kim (1992) have claimed that, to develop an analysis of dynamic response for moving systems need proper consideration for both aspect, gross body motion and small elastic deformation of flexible component, without neglecting coupling effect between these two mode of dynamic behaviour. Dynamic response of a vehicle is describing shock absorbing system which is inducing the whole body vibration. For lightweight vehicle without shock absorbing systems, tire and chassis frame have to function as shock absorbing. Using flexible multi body dynamic method, the use of aluminium as a material for lightweight vehicle chassis can be explored through dynamic response analysis. Simulation of virtual problem has been applied in this study to describe vibration phenomena occurred to the aluminium chassis. The chassis is linked to the tire by using the connector features in CAE software. Vibration signals while tire rolling on road bumper is measured for acceleration, velocity and displacement. The results indicate that, vibration is transmitted from road profile to the components of the vehicle trigger dynamic response of aluminium chassis structure.

1.2 Problems Statement.

In the current situation, where fuel economy is increasing and the global warming issue, the automotive industry has facing huge challenge to produce high fuel efficiency vehicle. Automakers are looking for extensive solutions through various ways such as reduced mass of the vehicle body. Mass reduction of the vehicle body is the essential factor in lessen gasses emission. This is because heavier vehicle need more energy to accelerate compare with lighter vehicle. Lightweighting has a lot of benefit but the application faced some difficulty when it comes to certain level like design, process, and materials. Among others material, Aluminum possess the characteristic that suit to manufacture lightweight chassis structure such as low density and high ductility. Chassis structures are the major structure that carry various vehicle accessories, sophisticated engines and also support human body. The disturbance forces from the flexible components and road surface are contributed the vibration transferred to human body through chassis structure. Excessive vibration exposure to human body can affect human health. Lightweight chassis structure without suspension systems such as go-kart vehicle can produce high vibration even though from the low impact source. Although the structure comes with minimal disturbance and good design, however still facing vibration problem when assemble into a vehicle. Therefore, it is crucial to develop an accurate model for analyzing the dynamic response to control the vibration of lightweight vehicle chassis.

1.3 Objectives

The objective of this study is to evaluate the possible approach of using aluminum as a lightweight vehicle chassis through the evaluation of dynamic response of the vehicle chassis. In order to achieve this objective, the following objectives are stressed out:

i. To develop multi body model which is incorporates vibrational effect into the systems.

ii. To conduct experimental works for the purpose of validating simulation model.