UNIVERSITI PUTRA MALAYSIA

CRASH DEFORMATION SIMULATION OF TUBULAR STRUCTURE TO DETERMINE AUTOMOTIVE CENTRE OF GRAVITY

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Crash Deformation Simulation of Tubular Structure to Determine Automotive Centre of Gravity

By

REZA AFSHAR HOSSEINABADI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

To my dear parents

and

lovely wife

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

Crash Deformation Simulation of Tubular Structure to Determine Automotive Centre of Gravity

By

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September 2009

Chairman: **Aidy Ali, PhD**

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In this study, the effects of crush behaviour of tubular structures have been investigated throughout simulation work. The axial crush was performed to predict the behaviour of tubular structures in terms of displacement of centre of gravity (COG) and mass moments of inertia (I_{yy} and I_{xz}).

Crush simulation includes two sections; close and open cross-sections respectively. In the case of close cross-sections, a displacement of COG of tubular structures with various polygonal cross-sections is numerically investigated under axial crush using program code of ANSYS/LS-DYNA. A subroutine is developed using this code to calculate the COG of deformed shape, during and after crush condition. The effect of wall thickness on displacement of COG is also investigated. Subsequently, a

procedure to find real time COG of tubular structure during and after crush is developed. Base on this procedure, a macro is added in the frame work of ANSYS/LS-DYNA to study the deformation behaviour of tubular structure by the accurate criteria of COG, I_{yy} and I_{xz}. Furthermore, the optimum number of edge of polygonal cross-section to have a reasonable symmetric deformed shape during crush is determined. It is found that the effect of number of polygonal edges on symmetric deformation of COG becomes more prominent as wall thickness of tubular structure decreases. The higher number of edges stabilizes the deformation shape.

To examine the open cross-sections, the tubular structures with various Cee-shaped cross sections are numerically investigated. The subroutine used for the first section is performed again. Yet, the effect of wall thickness was also studied. Subsequently, the effect of opening angle of Cee becomes more prominent as the wall thickness of the structure decreases. As the thickness increases, displacement of the COG in crush direction almost stabilizes for all opening angle of Cee in the range of $10^0 - 90^0$ degrees. Furthermore, variation of I_{yy} of structure with thicker wall for different cases of applied mass is approximately identical. As a contribution to real application, Cee-shaped cross-sections with higher wall thicknesses can be used in the form of frame structures in automotive industry in order to reduce the overall weight of the structure and therefore, to save more energy.

The study is the continue by incorporating a developed subroutine that added in the pre-processing module, in the frame work of ANSYS, distribution of the extra mass according to specific assigned COG and calculation the first bending and torsional natural frequencies of the simplified model in order to maximize these frequencies with final mass constraint was successfully investigated. It was found that adding the extra mass symmetrically about longitudinal axes of Body In White (BIW), higher values for first bending and torsional natural frequency is achieved.

Abstrack tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master of Sains

Simulasi Deformasi Remuk Struktur Berongga Bagi Penentuan Pusat Graviti Automotif

Oleh

REZA AFSHAR HOSSEINABADI

September 2009

Pengerusi: **Aidy Ali, PhD**

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Didalam kajian ini, kesan sifat remukkan struktur berongga dikaji dengan menggunakan kaedah simulasi. Remukkan arah menegak dijalankan bagi menjangka anjakan pusat gravity (COG) dan momen inersia (I_{yy} and I_{xz}).

Simulasi remuk kesan hentaman ini dibahagikan kepada dua bahagian: tertutup dan terbuka. Bagi kes tertutup, COG untuk struktur dengan polygonal keratin rentas dikaji secara berangka. Menggunakan program kod ANSYS/LS-DYNA. Sebuah pengatur caraan program di talis untuk mengukun COG bagi perubahan bentuk, ketika dan selepas hentaman. Kesan ketebalan struktur berongga ini juga dikaji. Seterusunya, kaedah mentukan COG secara seuanasa juda dibangunkan. Berasaskan kaedah ini, makro ditambah didalam rangka ANSYS/LS-DYNA untuk mengkaji

sifat deformasi tiub COG, $I_{yy}\ and\ I_{xz}$. tambahan lagi, segi optimum poligonal keratan rentas memiliki remukkan bentuk simetri. Di dalam kajian ini, didapati jumlah segi poligonal adalah signifikan apabila ketebalan meningkat. Semakin tinggi jumlah segi, semakin stabil keadaan remukkan.

Untuk mengkaji kes keratin rentas terbuka, tiub dengan beberapas bentuk Cee terbuka diuji. Pengatucaraan yang sama untuk kes tertutup digunakan sekali lagi. Kesan tebelatan juga dikaji. Kesan ketebales semakin jelas, anjakan COG disetuap arah semakin stabil untuk setiap sudut $10^0 - 90^0$ darjah. Tambahan lagi, variasi I_{yy} dengan beban yang seragan ditemui serupa. Sebagai sumbangan applikasi, bentuk Cee dengan ketebalan tinggi boleh digunakan untuk struktur automotive bagi mengurangkan berat seteterusnya tenaga.

Kejuan ini diteruskan dengan menanbahkan pengatucaraan didalam per proses modul, didalam ANSYS, taburan lebihan beban mengikut keperluan spesifik COG, dengan mengira lenturan dan puntiran frekuensi asli, didalam model yang diubah suai, bagi memaksimumkan kekangan beban. Didapti, penanbahan beban secara simetri di ats poksi memanjang di badan automotif, lenturan dan puntiran frekuensi dicapai.

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APROVAL

I certify that a thesis Examination Committee has met on 8 September 2009 to conduct the final examination of Reza Afshar Hosseinabadi on his thesis entitled "Crash Deformation Simulation of Tubular Structure to Determine Automotive Centre of Gravity" in accordance with Universities and University Colleges Act 1971 and Constitiuation of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the candidate be awarded the Master of Science.

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been fully acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

REZA AFSHAR HOSSEINABADI

Date: 23 November 2009

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LIST OF ABBREVIATIONS

BIW	Body In White
COG	Centre Of Gravity
COM	Centre Of Mass
CAE	Computer Aided Engineering
FEM	Finite Element Method
FE	Finite Element
MDO	Multi Design Optimization
APDL	Ansys Parametric Design Language
NGV	Natural Gas Vehicle

CHAPTER 1

INTRODUCTION

1.1. Introduction

The performance of vehicle in the event of collision is one of the most prominent areas that must be considered at the design stage. For instance a dangerous situation resulting in injury of the occupants can occur if the deformation of vehicle body members extends into the passenger compartment. To ensure adequate occupant protection, the crash energy must be absorbed through a deformation of front-end of automotive body structure.

All of the members, including the front-end and side members, particularly, play a major role in absorbing crash energy. Therefore, rising up their energy absorption efficiency is an important key point in improving the crashworthiness of the vehicle's front-end. The side members are generally structured as thin-walled components which have square, rectangular or hat-shaped cross-sections. It is generally curved positioned below the passenger compartment due to their positional relationship with the suspensions and other parts. However its front portion needs to be kept as straight as possible in order to make them capable to withstand greater loads. It is evident that the ability of side members to absorb energy is efficiently increased by proper design so that the collapse will be in predicted manner with preventing their side walls collapse in bending. This type of collapse mode can be engineered through several innovative techniques such as placing beading or reinforcements at appropriate place along the side members.

Furthermore, it was found that aluminium columns are also connected to the vehicle bumpers as a crush boxes to protect the passengers and the structure itself under impact loading. The aluminium columns are used to absorb the initial kinetic energy and keep the force level sufficiently low, so that lead to prevent from damage to the front-end compartment. Generally, the energy absorption will take place by extensive folding and bending collapse of the column wall. A specific characteristic of such a deformation mechanism is obtained when the rate of energy dissipation is located over the narrow zones, while the rest of the structure experiences a rigid body motion. At present, an increased of interest on vehicle safety have led to a comprehensive research [1] of the crash response of aluminium tubes from all aspects, experimental, analytical and numerical means. In this study, the Finite Element Method (FEM) was used to locate the centre of gravity (COG) of such tubular structures during and after axial crush deformation in order to have an accurate situation of deformed shape concerning the COG. Further more it will lead to come out with proper criteria to decide on the behaviour of tubular structure in term of deformation shape.

1.2. Research Problem

Thin-walled tubular structures are commonly used as the strengthening members in an automotive Body In White (BIW). Many researchers [2-20] have paid considerable attention on the crush behaviour of tubular structure for the past two decades. There have been a lot of activities on dynamic crush of tubular structures during recent years and most of them have been concerned with the energy absorbing systems of vehicles [21-29].

Assessing the general deformed shape of tubular structure during crush has been performed based on visual observation. However, this deformation is accessible in finite element simulation, having an accurate situation of deformed shape concerning the COG of structure was the lack of studies. Hence having a subroutine in FEM will help the researchers to obtain the inertia properties of arbitrary tubular shapes during and after crush deformation, and evaluate the accuracy of phenomenon of deformed shape of tubular structure during and after crush.

A number of automobile manufacturers have developed and produced all-aluminum bodies as a means of weight reduction [67]. Hence, examining the deformation behavior of various tubular structures made of aluminum by means of variation of their COG during and after crush deformation will help to extend the application of light materials for automotive BIW.

Furthermore, the correct location of COG is prominent for engineers in Computer Aided Engineering (CAE) analysis, when it comes to vehicle yaw, moment and rotation due to impact. Yet again, at design stage, mass in CAE model should be evenly distributed in order to obtain the correct COG. For instance, by having some extra parts in new designs such as adding fuel tanks in Natural Gas Vehicle (NGV), having the correct COG is a very prominent issue.

1.3. Research Objectives

The objectives of the study are:

1. To develop an algorithm that can auto adjust the location of COG of deformed shape, during and after crush.

2. To simulate the real time location of COG of the tubular structure during and after axial crush.

3. To develop a subroutine to distribute the extra mass according to specific assigned COG and access the first bending and torsion natural frequencies of the simplified model in order to maximize these frequencies with final mass constraint.

1.4. Scope of the Study

The study involves finite element simulation of crushing the tubular structures with different polygonal and open cross-sections, incorporating the subroutine integrated to the post processing module, in the framework of ANSYS/LS-DYNA. The experimental determination of COG location during deformation is not covered in the scope. The verification of the developed modelled was carried out based on analytical establish calculation.

1.5. The Layout of this Thesis

This thesis consists of five chapters including the introduction in Chapter 1, followed by literature review on Chapter 2. The literature review is covered from the previous works have been performed by many researchers on analysis of tubular structures subjected to crushing using different approaches, including: experimental, theoretical and FEM. The COG definition and different methods used in determining COG also discussed in this chapter.

Chapter 3 discusses the methods used and finite element analysis procedure involved. In addition the procedures of subroutines that added in the post-processing and pre-processing module of ANSYS/LS-DYNA code to calculate COG of deformed shape and adjust the COG in specified location are also discussed. Chapter 4 presents the results and discussion of the results. Chapter 5 highlights the contribution to new study, conclusions and recommendations for future work.

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