Faculty of Mechanical Engineering

THE EFFECTIVENESS OF ACTIVE FRONT BUMPER SYSTEM FOR FRONTAL IMPACT PROTECTION USING MAGNETORHEOLOGICAL DAMPER

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ABSTRACT

This research introduces a non-parametric modeling of a magnetorheological (MR) damper under impact its uses as a frontal impact protection device in active front bumper system. The research is started with the development of vehicle crash model for the impact testing. The concept of vehicle crash model including with the equation of motion such as impulse and momentum equation is derived. This study is aimed to model the behavior of a magnetorheological (MR) damper under impact loading through polynomial approach. The polynomial model is developed based on curve fitting from experimental results which consists of three regions namely fluid locking, positive and negative acceleration regions. The experimental results obtained from the impact test apparatus are evaluated in the form of transmitted force in time, velocity and displacement domains. The simulation results of the proposed polynomial model are then validated with the experimental results. The validated model is used to develop an inner loop controller by implementing a close-loop PI control to track the desired damping force through simulation. The governing equations of motions of vehicle collision and MR damper model are then integrated with the well known control strategy namely skyhook control. The performance of skyhook control is then compared with the vehicle with passive damper and common vehicle by using computer simulation in order to reduce the acceleration and the jerk of the vehicle during collision. As the result the skyhook control is significant to reduce the vehicle acceleration more than 20% and the jerking up to 40% compared with common vehicle.

ABSTRAK

Kajian ini adalah mengenai permodelan peredam magnetorheological (MR) dan kegunaannya sebagai peranti pelindung impak hadapan di dalam sistem bamper aktif hadapan. Kajian dimulakan dengan permodelan kenderaan bagi ujian pelanggaran. Penerangan mengenai permodelan tersebut berlandaskan konsep pergerakan kenderaan tersebut dengan menggunakan persamaan impulse dan momentum yang berlaku pada pelanggaran tersebut. Kajian ini mensasarkan pada permodelan karakteristik peredam magnetorheological (MR) terhadap impak yang diberi dengan menggunakan kaedah polinomial. Permodelan polinomial dihasilkan melalui lengkung keputusan eksperimen yang mengandungi tiga kawasan iaitu bendalir terkunci, positif dan negatif pecutan bendalir. Keputusan eksperimen yang diperoleh adalah daya sebaran oleh peredam MR dalam masa domain, daya sebaran dalam halaju domain dan daya sebaran dalam sasaran domain. Prestasi permodelan polinomial akan dibandingkan dengan keputusan eksperimen berkenaan. Kawalan daya sejajar bagi simulasi dilakukan dengan menggunakan kawalan PI dan ianya menunjukkan peredam MR dapat menghasilkan daya yang sejajar dengan daya yang dimahukan. Persamaan pergerakkan dihasilkan melalui kawalan skyhook. Prestasi kawalan skyhook akan dibandingkan dengan peredam pasif dan sistem biasa bamper kenderaan dalam mengurangi pecutan dan kejutan kenderaan semasa pelanggaran melalui simulasi berkomputer. Keputusannya kawalan skyhook berupaya mengurangkan pecutan kenderaan selepas kemalangan lebih 20% dan kejutan kenderaan lebih dari 44% berbanding dengan sistem biasa bamper kenderaan.

APPROVAL

DECLARATION

I declare that this thesis entitle "*the Effectiveness of Active Front Bumper System as Frontal Impact Protection Using Magnetorheological Damper*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :....................................

Name : Alif Zulfakar bin Pokaad

Date :....................................

DEDICATION

To my beloved father, mother, sister and brother

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In the name of Allah the Most Gracious.

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M_p	Pendulum mass
M_v	Vehicle mass
M_b	Bumper mass
fr	Friction force of tire
dt	Time interval over which the force is applied
F_{dm}	Damper force
C_d	Damping constant for passive damper
g	Gravity acceleration
h	Height of pendulum
$\dot{Z}_b$	Velocity of the bumper after collision
$\ddot{Z}_b$	Acceleration of the bumper after collision
$\dot{Z}_v$	Velocity of the vehicle model after collision
$\ddot{Z}_v$	Acceleration of the vehicle model after collision
μ	Coefficient of friction
e	Coefficient of restitution
$F(t)$	Transmitted force by MR damper
α, γ	Parameters to control the shape of hysteresis
$\dot{x}_h$	Parameters to controls width
f_s	The offset force due to the accumulator
a_m	Dimension less parameter for transmitted force at each mass of pendulum
f_d	Damping force at mass of pendulum 25 kg

I	Current input
$v(t)$	Velocity of the damper
β_m	Dimension less parameter for velocity of the damper
v_d	Velocity of the damper at mass of pendulum 25 kg
F_{peak}	Maximum transmitted force at each of pendulum mass
v_{peak}	The peak velocity of the damper at each pendulum mass
t_c	Time contact between bumper and pendulum
a_i	Experimental coefficient of force transmitted in fluid locking region
b_i , c_i	Obtained from the slope and the intercept in fluid locking region
d_i , g_i	Experimental coefficient of positive acceleration region
e_i , f_i , h_i , p_i	Obtained from the slope and the intercept in positive acceleration region
j_i , m_i	Experimental coefficient of negative acceleration region
k_i , q_i , n_i , r_i	Obtained from the slope and the intercept in negative acceleration region
F_d	Desired damping force
F_a	Actual damping force
K_p	Proportional constant
K_i	Integral constant
F_s	Semi-active damper force
$F_{maximum}$	Maximum force in each pendulum mass
C_{sky}	Damping coefficient for skyhook

CHAPTER 1

INTRODUCTION

1.1 Introduction

Vehicle bumper is usually designed to withstand an impact of collision at relative velocity of 5 to 15 km/h without having a major damage to the bumper (Buechele *et al.*, 2004). Many conventional bumpers use a stationary impact absorbing structure that is designed to deform permanently in order to prevent collateral damage toward vehicle frame as well as others vehicle components.

In this study active bumper system using magnetorheological (MR) dampers is attached between the chassis and front bumper and is used to reduce the crash impact. The main part in MR damper is a controllable fluid that has an ability to reversibly change from a free-flowing, linear viscous fluid to a semi-solid in milliseconds through controllable yield strength when exposed to a magnetic field (Spencer *et al.*, 1996).

During collision, the data acquisition device will send rapid signals to the MR dampers controller. The central processor in the vehicle analyzes the data prior sending appropriate control signal to the active bumper system. The input of the MR damper is in the form electrical current that sent through the coils in the MR damper. This will generate an electromagnetic field and yet affect the MR fluid viscosity which therefore changes the damping coefficient accordingly. All of this happened instantaneously of which reduce the impact force produced during collision.

The intention of this study is to investigate the effectiveness of active front bumper system with an intention to reduce an acceleration and jerk of the vehicle during collision. The active front bumper system is designed to reduce the collision impact through the MR damper that has the ability to change its damping coefficient based on the command input from the MR damper controller. The damping coefficients of MR damper have to be adjustable in real time to better achieve energy absorption of collision impact. Therefore, the semi-active control law can be explored through simulation that includes the development of an impact loading test rig, MR damper modeling and its validation under impact loading as well as inner-loop and outer-loop control design for the active bumper system.

The present study begins from modeling of vehicle crash test on computer simulation. MR damper test rig and vehicle crash test rig are then developed for MR damper testing and vehicle collision evaluation. Then, both validated models will be used to implement the controller structure for active front bumper system by using the computer simulation. Finally, potential benefits of implementing the active front bumper system using MR damper are evaluated in terms of reducing the acceleration and jerk of the vehicle during collision. The jerk can be defined as the derivation of the vehicle acceleration to the time of the collision.

1.2 Problem Statement

Current bumper design is not effective in absorbing the total amount of energy during front collision since it is fixed directly to the chassis. Thus, energy of collision will be fully transferred from the front bumper to the vehicle chassis. The collision energy transferred to the chassis can cause the driver and the front passenger to get serious injury resulting to