UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

MODELLING AND CONTROL OF A SEMI-ACTIVE MAGNETORHEOLOGICAL DAMPER FOR ENGINE MOUNTING SYSTEMS

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MODELLING AND CONTROL OF A SEMI-ACTIVE MAGNETORHEOLOGICAL DAMPER FOR ENGINE MOUNTING SYSTEMS

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A thesis submitted
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Faculty of Mechanical Engineering

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DECLARATION

I declare that this thesis entitled “Modelling and Control of a Semi-Active Magnetorheological Damper for Engine Mounting Systems” is the result of my own research except as cited in the references. This thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature : ……………………………….….
Supervisor Name : DR. AHMAD KAMAL BIN MAT YAMIN
Date : ………………………………..

DEDICATION

To my beloved father, mother, wife, brothers, sisters, friends, lecturers and Allah S.W.T.

ABSTRACT

Multiple operating modes in advanced automotive powertrain technologies such as hybrid propulsion and cylinder deactivation require adaptable engine mounting systems. The use of magnetorheological (MR) fluid dampers for semi-active engine mounting systems offers the prospect of reducing the engine vibration by providing controllable damping forces. Controlling the semi-active engine mounting systems is challenging. The control should not only adequately provide the desired damping forces but also account for the vibration reduction. The aim of this study are to develop a force tracking control for a MR fluid damper model based on the characteristics obtained from the measurements and to assess the effectiveness of the vibration reduction control applied to the semi-active engine mounting system. The MR fluid damper unit was built in-house and was characterized using a damping force test rig. Based on the empirical data, the force tracking control was modelled based on the PI controller in Matlab Simulink software to provide desired damping forces. With sinusoidal forces generated by an electric motor, a scale model of three-degree-of-freedom (3-DOF) passive engine mounting system was built in-house to verify a mathematical model developed using the software. Then the 3-DOF model was added with the MR fluid damper model and the vibration attenuation control was applied to the semi-active engine mounting system using the Fuzzy-Tuned-PID controller. The results show the controller gives improvements in terms of Root mean square (*RMS*) and maximum peak variation as compared to the passive system.

ABSTRAK

Kepelbagaian mod operasi dalam teknologi sistem kuasa automotif termaju seperti penggerak hibrid dan penyah-aktifan silinder memerlukan sistem pelekap enjin boleh suai. Penggunaan peredam bendalir magnetorheological (MR) pada sistem pelekap enjin separa-aktif menawarkan prospek untuk mengurangkan getaran enjin dengan menyediakan daya peredam yang boleh dikawal. Pengawalan sistem pelekap enjin separa-aktif adalah mencabar. Kawalan itu bukan sekadar memberikan daya redaman yang secukupnya tetapi perlu juga mengambil kira pengurangan gangguan. Tujuan kajian ini adalah untuk membangunkan kawalan penjejakan daya untuk model peredam bendalir MR berdasarkan ciri-ciri yang diperolehi daripada pengukuran dan menilai keberkesanan kawalan pengurangan gangguan yang digunakan untuk pelekap enjin separa-aktif. Satu model unit perendam bendalir MR dibina di makmal dan dicirikan menggunakan sebuah pelantar ujian daya peredam. Berdasarkan data mengukuran tersebut, kawalan penjejakan daya berasaskan kawalan PI dibangunkan dengan menggunakan perisian Matlab Simulink bagi memberikan daya redaman yang diingini. Dengan menggunakan daya sinusoidal yang dijana daripada elektrik motor, satu model tiga darjah kebebasan (3-DOF) sistem pelekap enjin pasif juga dibina bagi mengesahkan model matematik yang dibangunkan menggunakan perisian tersebut. Model peredam bendalir MR telah dimasukkan ke dalam model 3-DOF dan kawalan pengurangan gangguan telah digunakan untuk sistem pelekap enjin separa-aktif menggunakan kawalan Fuzzy-Tuned PID. Keputusan menunjukkan kawalan tersebut memberikan peningkatan pada „Root mean square‟ (*RMS*) *dan variasi puncak maksimum berbanding dengan sistem pasif.*

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$\dot{x}(t)$ - Control state vector

A - The control system matrix,

B - The control input matrix,

$u(t)$ - The control system input,

Q - State weighting semi positive matrix.

R - Input weighting positive matrix.

K - State feedback gain matrix.

P - Solution of an algebraic Riccati equation.

$\dot{x}$ - Absolute velocity of engine.

$(\dot{x}-\dot{z})$ - Relative velocity between the engine and the chassis.

τ - Shear stress in the fluid,

τ_y - Yielding shear stress controlled by the applied field H,

η - Newtonian viscosity of the applied magnetic field,

$\gamma^{\cdot}$ - Shear strain rate

$\mathrm{sgn}(\cdot)$ - Signum function

η_r - elastic fluid properties

η - viscous fluid properties

k , m - Fluid parameters for Herschel–Bulkley model.

z - Time derivative in hysteresis loop, and the

β, γ , A and n - Parameters shape in the hysteresis loop

F$_{mr}$ - Damper force,

$a_i \; b_i \; c_i$ - Polynomial coefficients

n - Order of the polynomial

I^i - Current applied to MR dampers

v - Damper velocity.

$x_i(t)$ - Relative displacement over the entire response.

$x^{\max}$ - Maximum displacement response.

$d_i(t)$ - Inter-storey

J_1,J_2,J_3 - Evaluation criteria

α_c - Weighting coefficient

C_p , - Fitness value is positive.

μ - Penalty constant to scale the fitness function.

Z_s - Vertical displacement

θ - Moment pitch

α - Moment roll

Z_{sr} - Vertical displacement at right side of the frame structure.

Z_{sl} - Vertical displacement at left side of the frame structure.

Z_{sb} - Vertical displacement at back side of the frame structure.

Z_{sf} - Vertical displacement at front side of the frame structure.

$\dot{Z}_{sf}$ - Velocity at front side of the frame structure.

$\dot{Z}_{sb}$ - Velocity at back side of the frame structure.

$\dot{Z}_{sl}$ - Velocity at left side of the frame structure.

$\dot{Z}_{sr}$ - Velocity at right side of the frame structure.

$\ddot{Z}_{sf}$ - Acceleration at front side of the frame structure.

$\ddot{Z}_{sb}$ - Acceleration at back side of the frame structure.

$\ddot{Z}_{sl}$ - Acceleration at left side of the frame structure.

$\ddot{Z}_{sr}$ - Acceleration at right side of the frame structure.

P, L - Width and Length of the frame structure.

a, b - Distance of the unbalance mass from center of gravity.

M_e - Mass of engine

M_u - Mass of unbalance mass

c_s - Damper

k_s - Spring

K_p - Proportional gain, a tuning parameter

K_i - Integral gain, a tuning parameter

K_d - Derivative gain, a tuning parameter

$e(t)$ - Error = $y_{(sp)}(t) - y(t)$

t - Time or instantaneous time (the present)

LIST OF ABBREVIATIONS

ABS	-	Antilock braking systems
AMB	-	Active Magnetic Bearing
AUV	-	Autonomous underwater vehicle
DAQ	-	Data Acquisition
DOF	-	Degree of Freedom
ER	-	Electrorheological
FAMNN	-	Fuzzy associative memory neural network
FGS-PID	-	Fuzzy gain scheduling of PID
FFNN	-	Feed forward neural networks
FNN	-	Fuzzy Neural Network controller
FPIDC	-	Fuzzy PID type controller
GA	-	Genetic Algorithm
HVAC	-	Heating, Ventilation and Air-Conditioning
LOG	-	Linear quadratic Gaussian
MF	-	Membership function
MIMO	-	Multi-Input-Multi-Output
MPPT	-	Maximum power point tracking.
MR	-	Magnetorheological
OSTFPID	-	Online smart tuning fuzzy PID
PID	-	Proportional Integrate Derivative

PV - Photovoltaic

RMS - Root Means Square

RNN - Recurrent neural networks

SIMO - Single-Input-Multi-Output

LIST OF PUBLICATIONS

M. Z. Sariman, M. Hafiz Harun, A. K. Mat Yamin, F. Ahmad, M. R. Yunos, *Magnetorheological Fluid Engine Mounts: A Review on Structure Design of Semi-Active Engine Mounting*, International Journal of Materials, ISSN: 2313-0555, Volume 2, 2015, pg. 6-16.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The engine mounting system in vehicles consists of engine, engine mounts and chassis. The primary functions of the engine mounting system are to support the weight of the engine and to reduce the transmission of engine vibration to the chassis. The motion of the engine block is strongly dependent upon the excitation forces from the engine.

There are two primary causes of the excitations. Firstly is due to the gas pressure forces associates with combustion and expansion of the fuel-air mixture. Secondly is attributed to the variable inertia associated with the reciprocating components within the engine. The gas pressure yields the principal force of disturbance at low engine speeds, while the inertia forces may be considerably larger at higher speeds. The use of engine mounts with low stiffness and high damping can attenuate the disturbance at low frequency and vice versa.

The engine mount system can be passive, semi-active or active. The active system is expensive since it requires an actuator, adequate sealing, moving parts, and possibly large amount of energy for the actuator. The semi-active mount offers significant improvements over passive isolator. The system benefits from the advantages of active systems with the reliability of the passive system. On the other hand, in case of failure on control system, the semi-active mount is able to work in the passive mode. In addition, the