



**Faculty of Mechanical Engineering**

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

**Mohamad Zaharudin Bin Sariman**

**Master of Science in Mechanical Engineering**

**2016**

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

**MOHAMAD ZAHARUDIN BIN SARIMAN**

**A thesis submitted  
in fulfillment of the requirements for the degree of Master of Science in  
Mechanical Engineering**

**Faculty of Mechanical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2016**

## 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.

Signature : .....

Name : MOHAMAD ZAHARUDIN BIN SARIMAN

Date : .....

## **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 pelepas enjin boleh suai. Penggunaan peredam bendalir magnetorheological (MR) pada sistem pelepas enjin separa-aktif menawarkan prospek untuk mengurangkan getaran enjin dengan menyediakan daya peredam yang boleh dikawal. Pengawalan sistem pelepas 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 pelepas enjin separa-aktif. Satu model unit peredam bendalir MR dibina di makmal dan dicirikan menggunakan sebuah pelantar ujian daya peredam. Berdasarkan data pengukuran tersebut, kawalan penjejakan daya berasaskan kawalan PI dibangunkan dengan menggunakan perisian Matlab Simulink bagi memberikan daya redaman yang diinginkan. Dengan menggunakan daya sinusoidal yang dijana daripada elektrik motor, satu model tiga darjah kebebasan (3-DOF) sistem pelepas 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 pelepas 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.*

## **ACKNOWLEDGEMENTS**

I would like to express my sincerest gratitude to my Principal supervisor Dr. Ahmad Kamal Bin Mat Yamin and Co-supervisor Ir. Mohamad Hafiz Bin Harun for their guidance, support, and constant encouragement during my study. I also would like to thank Mr. Fauzi Bin Ahmad and Mr. Md Razali Bin Yunos for their advices in this research. I gratefully acknowledge Universiti Teknikal Malaysia Melaka (UTeM) for their financial support via Short Term Grant Project (PJP/2013/FTK(3C)/S01156) in this research activity.

I would like take this opportunity to thank my colleagues at the Faculty of Mechanical Engineering, UTeM, Abdurahman Dwijotomo and Mohd Sabirin Bin Rahmat for their outstanding collaboration in the experimental works and also for being a very good sharing partner during my research. Thanks also to my other colleagues at Taman Tasik and Bukit Beruang for providing an enjoyable study environment.

Finally, my deepest grateful and thanks go to my parents, Sariman Bin Aris and Kamisah Binti Basiron, my dear siblings and my dear friends, Abdul Muhaimin Bin Mohd Shafie, Mohd Syahir Bin Ali, Mohd Zaini Bin Jamaludin, Mohd Hazrin Bin Ismail and Ashaffi'e Bin Mustaffa . Their continuous prays and moral supports have been brought me here.



## TABLE OF CONTENTS

| CHAPTER  | PAGE        |
|--|-------------|
| COVER PAGE   |             |
| DECLARATION  |             |
| APPROVAL   |             |
| DEDICATION   |             |
| ABSTRACT   | i           |
| ABSTRAK  | ii          |
| ACKNOWLEDGEMENTS   | iii         |
| TABLE OF CONTENTS  | iv          |
| LIST OF TABLES   | vi          |
| LIST OF FIGURES  | viii        |
| LIST OF APPENDICES                                       | xii         |
| LIST OF SYMBOLS  | xiii        |
| LIST OF ABBREVIATIONS                                    | xvi         |
| LIST OF PUBLICATION                                      | xviii       |
| <b>CHAPTER</b>   | <b>PAGE</b> |
| <b>1. INTRODUCTION</b>                                   | <b>1</b>    |
| 1.1 Introduction   | 1           |
| 1.2 Problem statement                                    | 4           |
| 1.3 Aim and objectives                                   | 8           |
| 1.4 Scope  | 8           |
| 1.5 Research flow  | 9           |
| 1.6 Thesis outlines                                      | 11          |
| <b>2. LITERATURE REVIEW</b>                              | <b>13</b>   |
| 2.1 Overview   | 13          |
| 2.2 Control structures for vibration attenuations        | 13          |
| 2.2.1 Control structure for force tracking               | 17          |
| 2.3 Operational modes of MR fluid                        | 19          |
| 2.4 Types of MR engine mounts                            | 21          |
| 2.4.1 Flow mode  | 22          |
| 2.4.2 Squeeze Mode                                       | 27          |
| 2.4.3 Mix mode   | 29          |
| 2.5 MR damper model                                      | 33          |
| 2.5.1 Formulation model                                  | 33          |
| 2.5.2 Empirical model                                    | 37          |
| 2.6 Parameter Optimization tools, Genetic Algorithm (GA) | 38          |
| 2.7 Summary  | 41          |
| <b>3. EXPERIMENTAL APPARATUS AND SETUPS</b>              | <b>42</b>   |
| 3.1 Overview   | 42          |
| 3.2 Prototype development of an MR damper unit           | 42          |
| 3.3 Operating principle of the MR damper                 | 44          |
| 3.4 Damping force test rig                               | 46          |

|           |   |            |
|-----------|---|------------|
| 3.4.1     | Drive unit  | 48         |
| 3.4.2     | Sensors   | 52         |
| 3.4.3     | Software  | 56         |
| 3.5       | 3-DOF engine mounting test rig  | 58         |
| 3.6       | Summary   | 62         |
| <b>4.</b> | <b>DEVELOPMENT OF FUZZY-PID CONTROLLER FOR A SEMI-ACTIVE ENGINE MOUNTING SYSTEM</b> | <b>64</b>  |
| 4.1       | Overview  | 64         |
| 4.2       | Control structure of the semi-active engine mounting system                         | 64         |
| 4.3       | Mathematical model of the engine mounting system                                    | 65         |
| 4.4       | Mathematical model of the MR damper   | 71         |
| 4.5       | Force tracking control of the MR damper   | 75         |
| 4.6       | Vibration attenuation   | 77         |
| 4.6.1     | PID controller  | 77         |
| 4.6.2     | Fuzzy-tuned PID controller  | 78         |
| 4.7       | Summary   | 83         |
| <b>5.</b> | <b>RESULTS AND DISCUSSIONS</b>  | <b>84</b>  |
| 5.1       | Overview  | 84         |
| 5.2       | The Effect of magnetic fields on damping force of the MR damper                     | 84         |
| 5.3       | Formulation of the MR damper  | 87         |
| 5.4       | Force tracking control  | 88         |
| 5.5       | Verification of the mathematical model of the 3-DOF passive system                  | 91         |
| 5.6       | Vibration attenuation of the semi-active system                                     | 93         |
| 5.7       | Summary   | 98         |
| <b>6.</b> | <b>CONCLUSIONS AND RECOMMENDATION FOR FUTURE WORK</b>                               | <b>99</b>  |
| 6.1       | Conclusions   | 99         |
| 6.1.1     | Verification of the mathematical model of the semi-active MR damper                 | 99         |
| 6.1.2     | The performance of the force tracking control                                       | 100        |
| 6.1.3     | The performance of the vibration attenuation controllers                            | 101        |
| 6.2       | Recomendation for future work   | 102        |
| 6.3       | Contributions   | 102        |
|           | <b>REFERENCES</b>   | <b>104</b> |
|           | <b>APPENDICES</b>   | <b>118</b> |

## LIST OF TABLES

| TABLE | TITLE  | PAGE |
|-------|--|------|
| 3.1   | Specifications of asynchronous motor.  | 49   |
| 3.2   | Specifications of variable-frequency drive.  | 50   |
| 3.3   | Specifications of gear reduction unit.   | 52   |
| 3.4   | Load cell sensor specifications.   | 54   |
| 3.5   | Bridge amplifier specifications.   | 55   |
| 3.6   | Wire transducer specifications.  | 56   |
| 3.7   | Experimental parameters.   | 60   |
| 3.8   | Electric motor specification.  | 60   |
| 3.9   | Accelerometer specification.   | 61   |
| 3.10  | Gyrometer specification.   | 62   |
| 4.1   | Simulink model parameters.   | 70   |
| 4.2   | Positive and negative acceleration equation.   | 73   |
| 4.3   | Coefficient of the sixth order polynomial model.   | 75   |
| 4.4   | Ziegler-Nichols tuning rule based on critical gain $K_{cr}$ and critical period $P_{cr}$ (Second Method). (Ogata, (2010)). | 78   |
| 4.5   | Constant values of membership function for output.   | 82   |
| 4.6   | Fuzzy logic rule for $K_p$ .   | 82   |
| 4.7   | Fuzzy logic rule for $K_i$ .   | 82   |
| 4.8   | Fuzzy logic rule for $K_d$ .   | 83   |

|     |   |    |
|-----|---|----|
| 5.1 | The optimised parameters for PID controller.  | 94 |
| 5.2 | Maximum peak variation of semi-active systems with respect to passive system.                   | 97 |
| 5.3 | RMS values of simulation results on PID and Fuzzy Tuned PID control compared to passive system. | 97 |

## LIST OF FIGURES

| FIGURE | TITLE  | PAGE |
|--------|--|------|
| 1.1    | Schematic of a Semi-Active vibration control.  | 2    |
| 1.2    | Research methodology.  | 10   |
| 2.1    | Basic close-loop control systems.  | 14   |
| 2.2    | The structure of force tracking control of MR damper<br>(Ubaidillah <i>et al.</i> , (2011)).   | 17   |
| 2.3    | The controller structure of semi-active suspension system<br>(Hudha <i>et al.</i> , (2005)).   | 18   |
| 2.4    | Schematic of the MR-damper-based semi-active system<br>(Wang and Liao, (2005)).  | 19   |
| 2.5    | MR Fluid operation (a) Flow mode, (b) Shear mode,<br>(c) Squeeze mode (Olabi and Grunwald,( 2007)).  | 20   |
| 2.6    | MR Fluid operation named “gradient pinch mode”<br>(Imaduddin <i>et al.</i> , (2013)).  | 21   |
| 2.7    | (a) Typical single pumper hydraulic engine mount (Tikani <i>et al.</i> , (2010))<br>(b) Double pumper hydraulic engine mount (Vahdati (1998)). | 23   |
| 2.8    | Simplistic model of a (a) single and (b) double pumper fluid mount<br>(Vahdati, (1998)).   | 23   |
| 2.9    | (a) Variable spring rate fluid mount design (b) Simplistic model<br>(Vahdati, (2005)).   | 24   |

|      |  |    |
|------|--|----|
| 2.10 | (a) Double notch passive hydraulic propose by Tikani <i>et al.</i> (2010)  |    |
|      | (b) Variable bottom chamber volumetric stiffness fluid mounts design<br>by Vahdati and Heidari (2010).   | 25 |
| 2.11 | Hydraulic mount with controllable inertia track: (a) cross section of a<br>hydraulic mount and (b) assembly components (Truong and Ahn, (2010)).   | 26 |
| 2.12 | Configuration of prototype mounts experiment (Barszcz <i>et al.</i> , (2012)).<br>(a) Schematic diagram with inertia track and orifice. (b, c, d and e)<br>design that use in the experiment (top view). | 27 |
| 2.13 | MR Fluid elastomers (Wang and Gordaninejad, (2009)).   | 28 |
| 2.14 | Mixed mode semi-active engine mount squeeze and flow mode (A)<br>Schematic diagram (B) Physical Model (Wang <i>et al.</i> , (2010)).   | 31 |
| 2.15 | MR fluid cell (El Wahed and Mcewan, (2011)).   | 31 |
| 2.16 | Mixed mode design proposed by Choi <i>et al.</i> (2008).   | 32 |
| 2.17 | Viscos-plastic models often used to describe MR fluids.  | 34 |
| 2.18 | Idealized biviscous constitutive relationship (Stanway <i>et al.</i> , (1996)).  | 36 |
| 2.19 | Control strategy for integrated fuzzy logic and genetic algorithms<br>(Yan and Zhou, (2006)).  | 39 |
| 3.1  | Schematic of MR damper.  | 43 |
| 3.2  | Prototype of MR damper.  | 43 |
| 3.3  | Flow mode operation in MR damper (not to scale).   | 45 |
| 3.4  | Prediction magnetic field of MR damper.  | 46 |
| 3.5  | Magnetic field along the orifice slit.   | 46 |
| 3.6  | Schematic diagram for experimental setup for the measurement of<br>damping force.  | 47 |
| 3.7  | Damping force test rig.  | 48 |

|      |   |    |
|------|---|----|
| 3.8  | Asynchronous motor.   | 49 |
| 3.9  | Variable-frequency drive.   | 50 |
| 3.10 | Power transmission belt.  | 51 |
| 3.11 | Gear reduction unit.  | 51 |
| 3.12 | Crank-slider assembly.  | 52 |
| 3.13 | Location for sensors attached to the test rig.  | 53 |
| 3.14 | FUTEK LCF 451 load sensor.  | 54 |
| 3.15 | Bridge amplifier.   | 55 |
| 3.16 | Celesco MT2A wire transducer.   | 56 |
| 3.17 | DAQ Board device PCI-6221.  | 57 |
| 3.18 | I/O connector block.  | 57 |
| 3.19 | Experimental setup description.   | 59 |
| 3.20 | Prototype of the test rig.  | 60 |
| 3.21 | KISTLER 8312B accelerometer.  | 61 |
| 3.22 | Gyrometer.  | 62 |
| 4.1  | Control structure model.  | 65 |
| 4.2  | Free Body Diagram Engine Mounting System (EMS).   | 67 |
| 4.3  | Simulink representation of MR damper model.   | 71 |
| 4.4  | Hard points of experimental data and linearization between two<br>hard points (Hudha <i>et al.</i> , (2005)).             | 73 |
| 4.5  | Example of the linear regression of the coefficients $a_i$ correspond to<br>the input current (refer more on Appendix D). | 74 |
| 4.6  | Structure of force tracking control of MR damper.   | 76 |
| 4.7  | PID control structure.  | 78 |
| 4.8  | Fuzzy Tuned PID control structure.  | 79 |

|      |  |    |
|------|--|----|
| 4.9  | Input and Output channel of Fuzzy logic control.   | 80 |
| 4.10 | Input membership function of chasis body vertical acceleration $V_{acc}$ .   | 81 |
| 4.11 | Input membership function of relative velocity of the chassis, $V_{vel}$ .   | 81 |
| 5.1  | Damping forces at a range of electrical currents.  | 86 |
| 5.2  | Force-displacement diagram at a range of electrical currents.  | 86 |
| 5.3  | Force-velocity diagram at a range of electrical currents.  | 86 |
| 5.4  | Force-velocity characteristics comparison.   | 87 |
| 5.5  | Force-displacement characteristics comparison.   | 88 |
| 5.6  | Simulation results of force tracking control at the excitation frequency of 1 Hz: (a) Sinusoidal, (b) Saw-tooth and (c) Square function. | 90 |
| 5.7  | Comparison between the simulation and experiment data for the vertical acceleration.   | 91 |
| 5.8  | Comparison between the simulation and experimental data for the pitch moment acceleration.   | 92 |
| 5.9  | Comparison between the simulation and experiment data for the roll moment acceleration.  | 92 |
| 5.10 | Vibration attenuations at 5 Hz.  | 95 |
| 5.11 | Vibration attenuations at 10 Hz.   | 96 |
| 5.12 | Vibration attenuations at 20 Hz  | 96 |



## LIST OF APPENDICES

| APPENDIX | TITLE  | PAGE |
|----------|--|------|
| A        | Detail drawing for MR engine mounting.                                     | 118  |
| B        | Calculation for determine the moment inertia rolling and pitching and COG. | 135  |
| C        | Detail drawing for test rig.   | 146  |
| D        | Linear regression of coefficient $a_i$ correspond to the input current.    | 149  |

## LIST OF SYMBOLS

|                       |   |   |
|-----------------------|---|---|
| $\dot{x}(t)$          | - | 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.       |
| $\tau$                | - | Shear stress in the fluid,                                  |
| $\tau_y$              | - | Yielding shear stress controlled by the applied field $H$ , |
| $\eta$                | - | Newtonian viscosity of the applied magnetic field,          |
| $\dot{\gamma}$        | - | Shear strain rate   |
| $\text{sgn}(\cdot)$   | - | Signum function   |
| $\eta_r$              | - | elastic fluid properties                                    |
| $\eta$                | - | viscous fluid properties                                    |
| $k, m$                | - | Fluid parameters for Herschel–Bulkley model.                |
| $z$                   | - | Time derivative in hysteresis loop, and the                 |

|                            |   |   |
|----------------------------|---|---|
| $\beta, \gamma, A$ 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   |
| $\alpha_c$                 | - | Weighting coefficient                                       |
| $C_p$                      | - | Fitness value is positive.                                  |
| $\mu$                      | - | Penalty constant to scale the fitness function.             |
| $Z_s$                      | - | Vertical displacement                                       |
| $\theta$                   | - | Moment pitch  |
| $\alpha$                   | - | 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.

**M. Z. Sariman**, M. Hafiz Harun, A. K. Mat Yamin, F. Ahmad, M. R. Yunos, *Vibration Control of a Passenger Car Engine Compartment Model Using Passive Mounts Systems*. ARPN Journal of Engineering and Applied Sciences, ISSN 1819-6608 (Online), Volume 10, 2015, No. 17

**M. Z. Sariman**, M. Hafiz Harun, A. K. Mat Yamin, F. Ahmad, M. R. Yunos, *Vibration Control of a Passenger Car Engine Compartment Model Using Passive Mounts Systems*. International Conference On Automotive Innovation Green Energy Vehicle Conference on 26-27 August 2014, Swiss Garden resort & Spa, Kuantan, Malaysia

# 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