VIBRATION ANALYSIS OF VEHICLE ENGINE MOUNTING

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Thesis submitted in fulfillment of the requirements
For the award of the degree of
Bachelor of Mechanical Engineering with Automotive Engineering

Faculty of Mechanical Engineering
UNIVERSITY MALAYSIA PAHANG

JUNE 2013

ABSTRACT

Engine mounting is one of the important components in a vehicle to isolate noise and vibration generated by the engine from the driver and passenger. There are three main types of engine mounting such as passive engine mounting, semi-active engine mounting and active engine mounting. The price of the mounting in the market range from the cheapest which is passive engine mounting to the most expensive type of engine mounting which is the active engine mounting. The effectiveness of the engine mounting vary with the price of the engine mounting with the passive engine mounting being the low quality isolation of noise, vibration and harshness (NVH) and the active engine mounting being the highest quality isolation of NVH. In order to reduce the vibrations, noise and harshness (NVH) level for vehicles, understanding about the vibration characteristics of the passive engine mounting in detail is crucial. The objective of this project is to analyze the vibration cause by the engine of a Perodua Kenari on the engine mounting system at different engine revolutions per minute (rpm). The experiment is carried out on a stationary vehicle using DasyLab software. Here, analysis on the vibration obtained from the experiment carried out helps to determine the time response and frequency response of the engine at different rpm. From the results obtained, we can understand the characteristics of the passive engine mounting which is the fundamental of engine mounting among the three types. By understanding the characteristics of the passive engine mounting, improvement can be made on the engine mounting in a low cost method to further improve on the NVH isolation quality.

ABSTRAK

Enjin ‘mounting’ merupakan salah satu komponen yang penting dalam sesebuah kenderaan untuk mengasingkan bunyi dan getaran yang dijanakan oleh enjin daripada pemandu and penunggangnya. Terdapat tiga jenis enjin ‘mounting’ yang utama seperti enjin ‘mounting’ pasif, enjin ‘mounting’ semi-aktif dan enjin ‘mounting’ aktif. Harga ‘mounting’ berbeza dari yang paling murah iaitu jenis enjin ‘mounting’ pasif kepada yang paling mahal iaitu jenis enjin ‘mounting’ aktif. Keberkesanan enjin ‘mounting’ berbeza mengikut harga jenis enjin ‘mounting’ iaitu kualiti pengasingan bunyi, getaran dan kekerasan yang rendah bagi enjin ‘mounting’ pasif dan kuality pengasing bunyi, getaran dan kekerasan yang tinggi bagi enjin ‘mounting’ aktif. Untuk mengurangkan lagi peringkat getaran, bunyi dan kekasaran pada kenderaan, permahaman terhadap ciri-ciri getaran pada enjin 'mounting' pasif adalah penting. Objektive projek ini adalah analisis pada getaran yang dijanakan oleh enjin Perodua Kenari pada sistem pemasangan enjin pada pusingan per minit enjin atas kenderaan yang statik dengan menggunakan perisian DasyLab. Di sini, analisis pada getaran yang diperoleh daripada eksperimen akan digunakan untuk menentukan masa tindak balas dan tindak balas frekuensi pada enjin untuk pusingan per minit enjin yang berbeza. Daripada keputusan yang diperoleh, pemahaman tentang ciri-ciri enjin ‘mounting’ pasif yang merupakan enjin ‘mounting’ yang paling asas, boleh didapati. Dengan memahami ciri-ciri tersebut, peningkatan dengan menggunakan cara yang murah boleh dibuat ke atas enjin ‘mounting’ pasif untuk mempertingkatkan lagi kualiti pengasingan bunyi, getaran dan kekerasan.

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LIST OF ABBREVIATIONS

a	Acceleration
ALGOR	General-purpose multiphysics finite element analysis software package
DasyLab	Data Acquisition System Laboratory
DAQ	Data Acquisition
DOF	Degree of Freedom
EFI	Electronic Fuel Injection
ER	Electro-rheological
F	Force
GP-IB	General Purpose Instrumentation Bus
IBM	International Business Machines
ICP	Incident Command Post
IEEE	Institute of Electrical and Electronics Engineers
IEPE	Integrated Electronics Piezoelectric
ISA	Industry Standard Architecture
Lab VIEW	Laboratory Virtual Instrument Engineering Workbench
LAN	Local Area Network
m	Mass
M	Moving mass
NI	National Instruments
NI-DAQ	National Instruments Data Acquisition
NVH	Noise, Vibrations and Harshness
PCI	Peripheral Component Interconnect

RS232	Recommended Standard-232
rpm	Revolutions per minute
USB	Universal Serial Bus
VI	Virtual Instrumentation

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Typically, an automotive engine-body-chassis system is subjected to many kind of forces which causes vibration to the vehicle such as unbalanced engine forces, uneven firing forces especially at idling speed, dynamic excitations from gearboxes and accessories, and road excitation. Connecting to the automotive engine-body-chassis system is a vehicle engine mounting system which consists of an engine and several mounts. Vehicles in the market now are made to be lighter in terms of structure and higher power output from the engine which causes high level of negative effect to the comfort of the passenger as the vibration and noise level will increase quite drastically.

As technology advances, engineers have come up with many different ways to isolate both noise and vibration generated by the engine from the driver and passenger. Current research and development efforts mainly focuses on improving the performance of engine mounting systems to achieve better vibration isolation, smooth automotive movement, and noise reduction as design trends nowadays are more towards compact and efficient automobiles which causes the engine-to-frame weight ratio and engine force densities to increased. The position of the engine mountings and the type of the engine mountings used are different in each automotive model. For Perodua Kenari 1000 cc electronic fuel injection (EFI) engine, it has three engine mounts that is located at the front, rear and right side of the engine. Common vehicle such as Perodua Kenari use passive engine mounting system.

Vehicle engine mounting system can be divided into three types; the active mounts, semi-active mounts and passive mounts. The system described here focuses on passive mounts, more precisely; elastomeric mounts where they can be designed to suit the necessary stiffness rate characteristics at all directions for proper vibration isolation as they are made of rubber. Among the three types of engine mounts, elastomeric mounts are the most cost-effective as they are made of rubber, compact and maintenance free.

1.2 PROBLEM STATEMENT

Although many vehicle companies are currently using elastomeric mounts to reduce the vibration and noise level for passenger cars, there are still other ways to use elastomeric mounts to fully optimize its function. In order to identify the level of vibration produce by the engine and the road condition, tests will be carried out on a straight road with different engine speed. Analysis will be done to identify the amount of vibration caused by the engine as well as the road condition. As semi-active mounts and active mounts control mechanism requires electronic devices to function, hence they cost more than the passive engine mounts. Besides that, the structure to build the semi-active mounts and active mounts are more complicated than the elastomeric mounts. Hence, production of these mounts will increase the price of the vehicles and the maintenance of the mounts will be costly. Also, in order to reduce the vibrations, noise and harshness (NVH) level for vehicles, understanding about the vibration characteristics of the passive engine mounting in detail is crucial.

1.3 OBJECTIVES

Objective for this project refers to the mission, purpose, or standard that can be achieved within the expected timeframe and with the available resources. The objective of this project is to perform an experiment on the engine of a Perodua Kenari to get the reading on the vibration data produced using DasyLab software. From the data obtained, analysis is made on the vibration cause by the engine of a Perodua Kenari on the engine mounting system at different engine revolutions per minute (rpm) on a stationary vehicle. By understanding the characteristics of the passive engine mounting, the attempt to reduce the vibrations, noise and harshness level of the vehicle can be made.

1.4 PROJECT SCOPE

The scopes for this project are to study about different types of engine mounting system and to try to understand the working principle in terms of functionality for specifically the passive mount made of elastomeric. Type of engine mounting system involved is the passive mount. For this project, DasyLab will be chosen as a measurement and instrumentation tool to acquire, and analyze the vibration caused by the engine on a stationary vehicle with different engine rpm.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will provide detail description of the literature review done according to the title analysis on the engine mounting system of Perodua Kenari. Tests will be carried out on the engine mountings of Perodua Kenari on straight road with different engine speeds. DasyLab will be used as the main measurement and instrumentation tool to acquire, simulate and analyze the vibration caused by the engine on a straight road with different engine rpm. Engine mountings can be divided into three which is active engine mount, semi-active engine mount and passive engine mount. As Perodua Kenari uses passive mounts as its engine mounting, therefore the focus will be on passive engine mounts. Passive engine mounting can be further divided into elastomeric mounts and passive hydraulic mounts.

2.2 PERFORMANCE REQUIREMENTS OF ENGINE MOUNTING SYSTEM

To support the weight of the engine is the main function of the engine mounting system. To ensure the engine can be freely maintained in its specific design position, the plan view location of the engine center of gravity should not only be contained within the support base, but the engine weight should also be well distributed among the load carrying mounts (M. Ahmadian et al. 1993; Anon, 1994; H. Ashrafruon et al. 1992; T. Ohara et al. 1989; S. Caladari and M. Demaio, 1994; T.G. Duclos, 1987; H. Eishima et al. 1987; W.C. Flower, 1995; D.M. Ford, 1985; G. Gallas and B. Renzo, 1985; P. L. Graf et al. 1988; H. Hata et al. 1987; R. Helber et al. 1990; Lisa, Hem, 1992; D.E. Ivers et al. 1992; S.R. Johnson and J.W. Subhedar, 1994; J.H. Kim and H.J. Yim, 1994). Other than to support the weight of the engine, the engine mounting system also functions to isolate the unbalanced engine disturbance force from the vehicle structure. As majority of the vehicles uses internal combustion engine, there exists two basic dynamic disturbances which is the firing pulse due to the explosion of the fuel in the cylinder and the inertia force and torque caused by the rotating and reciprocating parts such as piston, connecting rod and crank. Torque is acted on the engine block about an axis parallel to crank due to the firing pulses while inertia torque acts about an axis parallel to the crankshaft. The directions of the inertia forces are both parallel to the piston axis and perpendicular to the crank and piston axes (Yunhe Yu et al., 2001). Applying on a multi-cylinder engine which is commonly used in most vehicles, the components of the engine-unbalanced disturbance depends not only on the number of the cylinders in the engine but also the arrangement of the cylinders. For instance, there is a vertical inertia force acting on the engine block with addition to the oscillator torque about the crankshaft in a four-cylinder engine but in comparison to six- and eight-cylinder engines, inertia force is non-existence but only the torque oscillation. Figure 2.1 shows the engine disturbances excitation of an engine with six degree of freedom (DOF) vibration modes (P.E. Geck and R.D. Patton, 1984).

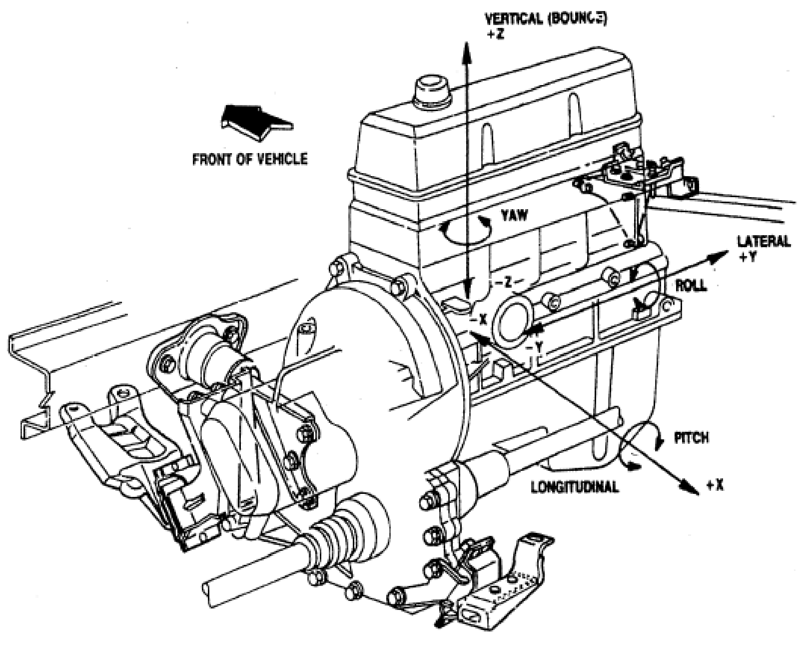

Figure 2.1: Engine six DOF mode

Source: P.E. Geck and R.D. Patton, 1984

For instance, engine pitch vibration is caused by the torque produced from the firing pulse in the engine cylinder. There are many causes that affect the frequency of unbalance disturbances as it is in correlation to the engine speed and depending on the number of cylinders in the engine. Besides that, the stroke number and the engine speed also affect the frequency of unbalance disturbances. For example, the frequency of fundamental disturbances for a four cylinder, four-stroke engine is at the second order of the engine speed which ranges around 20 – 200 Hz for an engine speed range of 600 – 6000 rpm. In comparison to an eight-cylinder engine which has frequency range of 40 – 400 Hz for the same engine speed range, the frequency of disturbance torque is at the fourth orders of the engine speed. Commonly, a disturbing shaking of vehicle is resulted from the engine disturbance at low engine speeds or near idle. At greater speeds, a sound similar to a boom is produced within the vehicle compartment when the disturbance force of the engine co-occurs with the resonances from the passenger compartment. The forces transmitted to the structure has to have low elastic stiffness and low damping to isolate the vibration caused by the engine unbalanced disturbances because they are proportional to the stiffness and damping of the mounts. The effect of frequency and damping on the force transmissibility through the typical two-element Voigt mount model is indicated in Figure 2.2. To avoid excitation of mounting system resonance during normal driving condition, the natural frequency of the mounting system in a certain direction should be below the engine disturbance frequency of the engine idle speed in order to obtain a low transmissibility. Maximizing the frequency of engine disturbance of mounting system natural frequency enables the engine mount stiffness coefficient to be as low as possible to obtain a low transmissibility. It is desirable to have a low transmissibility at a higher frequency range.

The transient response of the engine mount system can be chaotic for shock excitation if the elastic stiffness of an engine mount is too low as sudden acceleration and deceleration, braking and riding on uneven roads may causes shock excitation to occur. This kind of excitation is easily produced when the engine resonance mode is in the low frequency range. Large static and quasi-static engine displacement and damage to the engine components will occur due to low stiffness values. Therefore, in order to minimize the engine motion and absorb engine shake and resonance, high stiffness and high damping are required.

It is inferred that an engine mount system should be able to support the engine at static state, prevention of engine bounce from shock excitation and isolation of engine vibration that is caused by engine disturbances in the complete speed range. Figure 2.3 shows the dynamic stiffness of an ideal mount where the ideal mount supposed to be frequency-dependent (L.R. Miller and M. Ahmadian, 1992; D.A. Swanson and L.R. Miller, 1993). Engine mounts have to be 'soft' or have low elastic stiffness and low damping so that it can isolate the engine vibration at high frequency range. Even so, the engine mount also have to be 'hard' which is having high elastic stiffness and high damping in order to prevent engine bounce in the low frequency range. Other than being frequency-dependent, the engine mount system can also be amplitude-dependent as lower frequencies will lead to greater amplitude of displacement and vice versa.

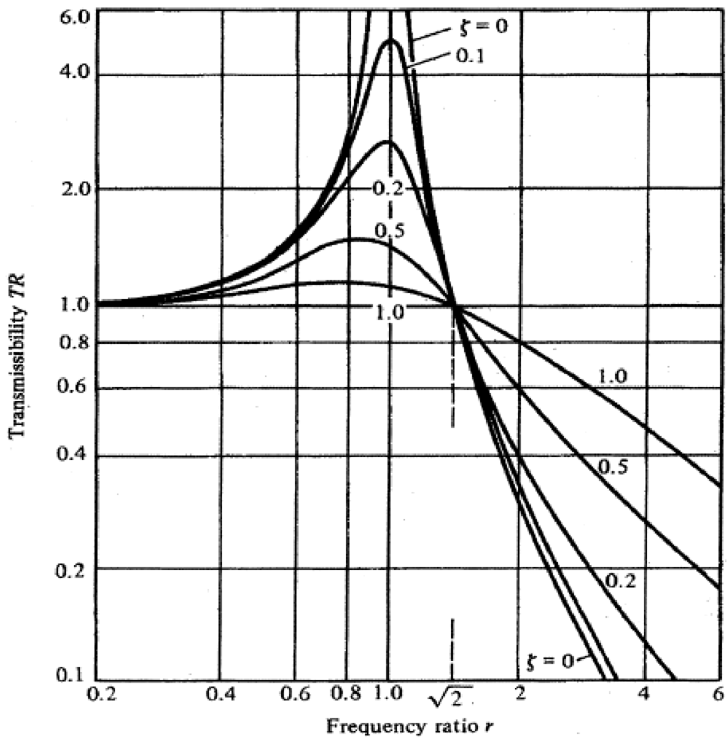

Figure 2.2: Effect of frequency and damping on the force transmissibility

Source: Yunhe Yu et al. 2001

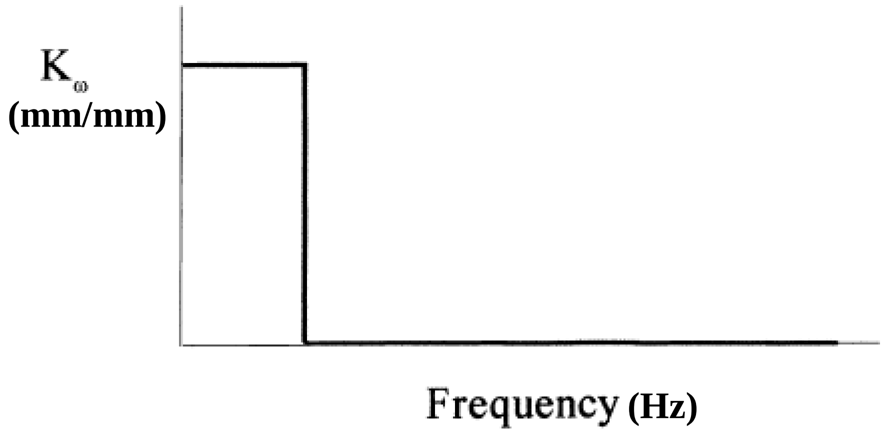

Figure 2.3: Dynamic stiffness of ideal mount

Source: Yunhe Yu et al. 2001

2.3 ACTIVE ENGINE MOUNTS

To suppress the transmission of the system disturbance force, a counteracting dynamic force is created by one or more actuators for active vibration control. To further explain more clearly, there should be an active energy source continuously supplied to the continuously generated target energy source as a counteraction to cancel off the vibration. The components that makes up an active engine mounts consist of a passive mount (elastomeric or hydraulic), force generating actuator, a structural vibration sensor and an electronic controller. The existence of the passive mounts in the construction of active mounts is as a precaution to support the engine in the event of an actuator failure. The actuator is use to provide a dynamic force to the vibration cause by the engine as it is reasonable in magnitude and the actuator reacts fast enough to the control signal. As for the structural vibration sensor, it is actually a force sensor or an accelerometer that sends the controlled signal to the controller which adjusts the amplitude and phase of the force generated by the actuator to reduce or minimized the measured sensor signal to reduce the vibration.

The passive mount stiffness (elastomeric and hydraulic) is equivalent to the stiffness of the active mount at every frequency exception to where the engine vibration occurs. Figure 2.4 and 2.5 shows the dynamic stiffness of elastomeric and hydraulic active mounts (L.R. Miller and M. Ahmadian, 1992). A tonal controller on the active mount structure will command the mount to be very soft at the disturbance frequency by reducing the accelerometer or force sensor signal thus the limitation of passive mounts, which is the ability of active elastomeric mounts to be very stiff at low frequencies and very soft at high frequencies, are overcome. Whereas the active hydraulic mounts can be tuned accordingly to achieve adequate damping at the engine bounce frequency and while being at higher frequency, it can have very low dynamic stiffness.

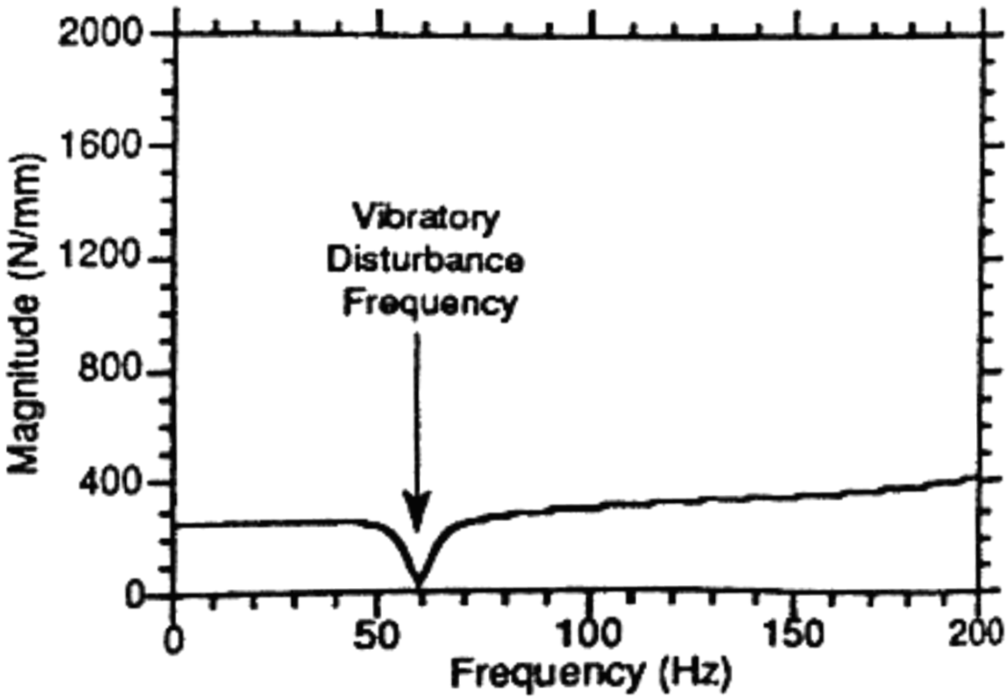

Figure 2.4: Dynamic Stiffness of an active elastomeric mount

Source: L.R. Miller and M. Ahmadian, 1992

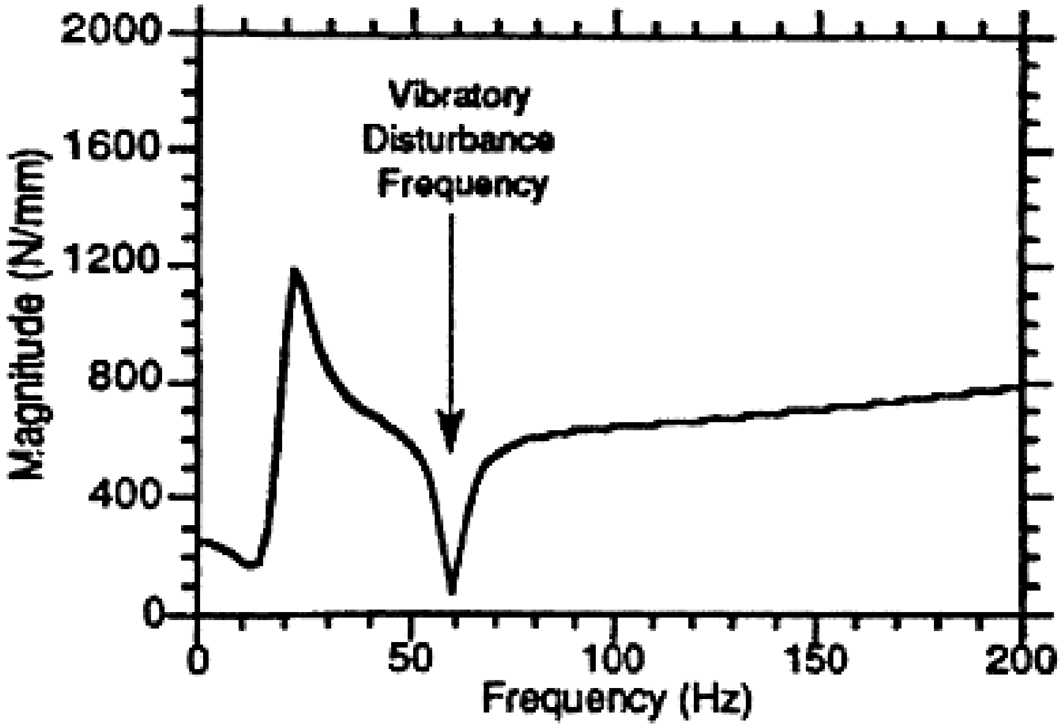

Figure 2.5: Dynamic stiffness of hydraulic active mount

Source: L.R. Miller and M. Ahmadian, 1992

2.4 SEMI-ACTIVE ENGINE MOUNTS

Semi-active engine mount is an engine mount with a semi-active control mechanism where through controlling system parameters such as elastic stiffness and damping, the semi-active control is able to change the dynamic response of the system. A common semi-active engine mount system consists of a passive mount with controllable elements and a control mechanism where majority of the semi-active mounts reported in the literature are of hydraulic type. Figure 2.6 shows a typical example of a mechanical model for a semi-active hydraulic mount where the moving mass M is adjustable according to the damping force so that the dynamic response of the system can be controlled. Meanwhile, Figure 2.7 shows a typical semi-active Electro-rheological (ER) mounts and its control system from where it is observe that the structure of it is similar to a conventional hydraulic mount except for the liquid which is an ER fluid and the orifices are in communication with one another and are made up of electrodes to which high voltage is applied.

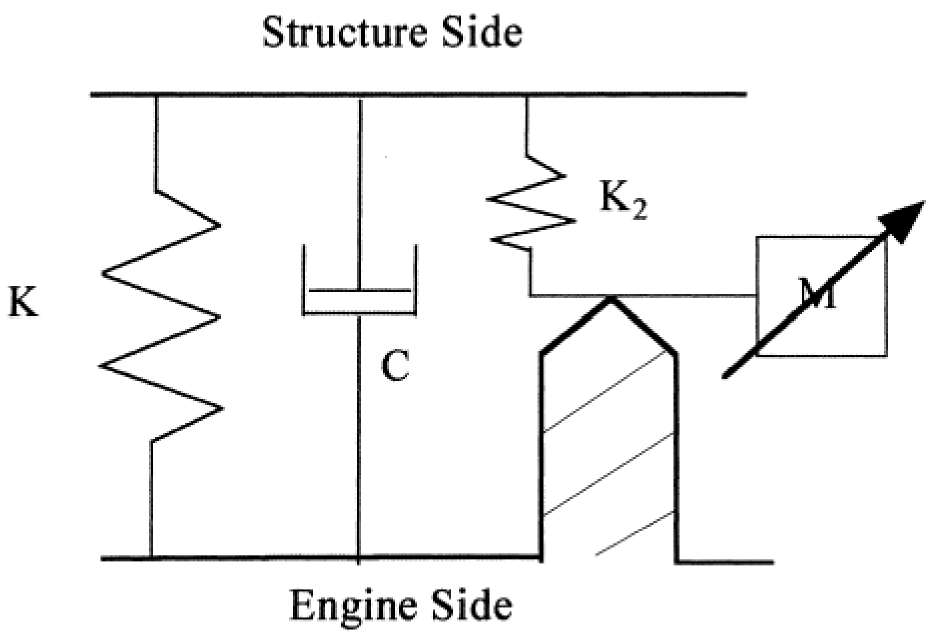

Figure 2.6: Mechanical model for semi-active hydraulic mount

Source: L.R. Miller and M. Ahmadian, 1992

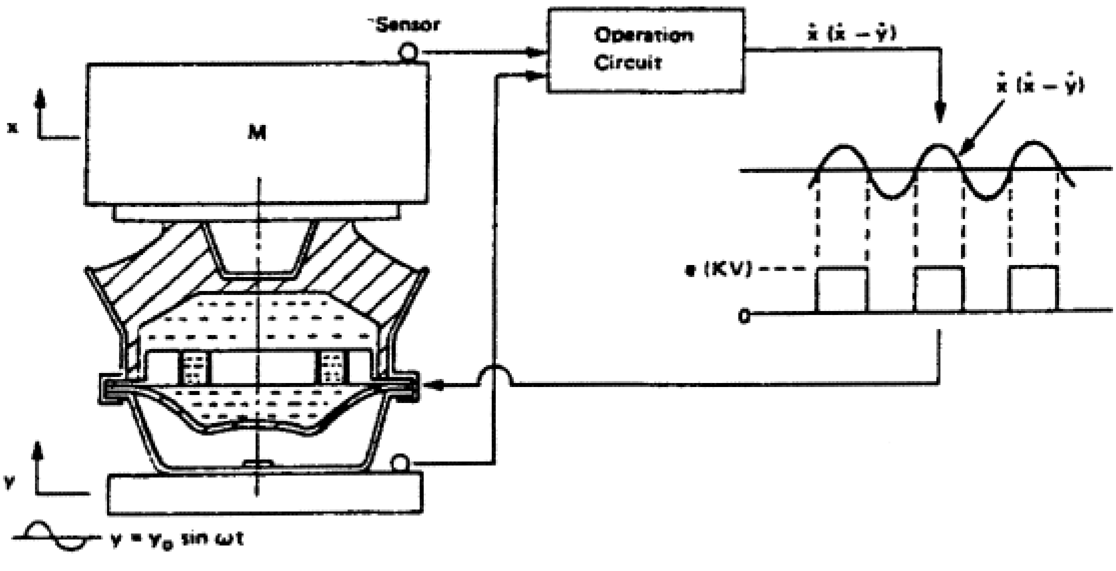

Figure 2.7: Semi-active control system for ER fluid filled mount

Source: T. Ushijima et al. 1988

Due to their rapidity of change in viscosity properties when apply to an electric field, ER fluid have drawn a lot of attention in the semi-active control of engine mounts as these properties enables the mechanism to control the damping of the system easily. When electric field strength is applied to the ER fluids, their apparent viscosity changes while by applying high voltage to the mechanism enables the selection of the control force of the damping force proportional to velocity where the applied voltage is adjusted in phase and in rectangular waveform.

2.5 PASSIVE ENGINE MOUNTS

2.5.1 Elastomeric Mounts

Since 1930s, elastomeric mounts have been used to isolate vehicle structure from engine vibration (H.C. Lord, 1930). From then onwards, there were much significant advancement in engine mountings to improve the performance of the elastomeric mounts. For proper vibration isolation, necessary elastic stiffness rate characteristics in all direction can be designed on the elastomeric mounts. Elastomeric mounts are more commonly used because they are compact, maintenance free and cost effective. For instance, the bonded type of elastomeric mounts is known to have more consistent performance and lasts longer. A Voigt model is usually used to represent the elastomeric mount. It consists of a spring and a viscous damper which is shown in Figure 2.8 (D.A. Swanson, 1993). Based on Figure 2.9, it can be concluded that the difficulty to design a mount system that satisfies the design requirements due to the dynamic stiffness of an elastomeric mount which increases as the frequencies increases due to damping. The performance of a high stiffness or high damping elastomeric mount will be poor on high frequency level but it has the ability to yield a low frequency shake level. Anyhow, this elastomeric mount can induce a high shake level at low frequency due to shock excitation from low noise levels produced by low stiffness and low damping. Therefore, the solution to the problem caused by low and high frequency level is to obtain a compromise between engine bounce and engine isolation which makes elastomeric mount the ideal engine mounting as it offers an adjustment between vibration isolation and static deflection.

Although elastomeric mounts have been favorably used for vehicle engine mounts for many years, but current vehicle development trend emphasizes on compact, light-weight, front wheel drive vehicles with low idle speed which requires the use of better performance mounts. Even so, such elastomeric mounts still have space for improvement. In order to obtain constant natural frequency in a broad weight-load range, it is desirable to use specific nonlinear stiffness characteristics, materials with high internal damping in addition to highly amplitude-dependent damping and stiffness.

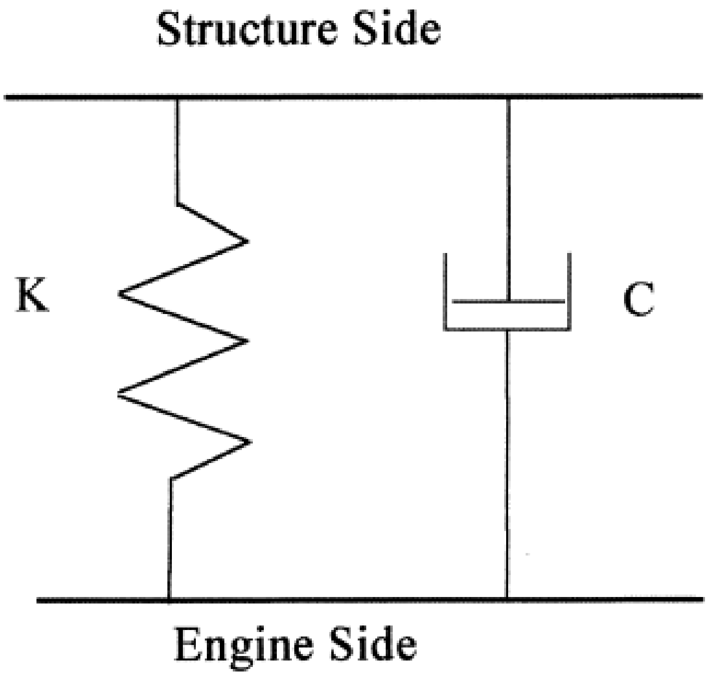

Figure 2.8: Mechanical model for elastomeric mount

Source: D.A. Swanson, 1993

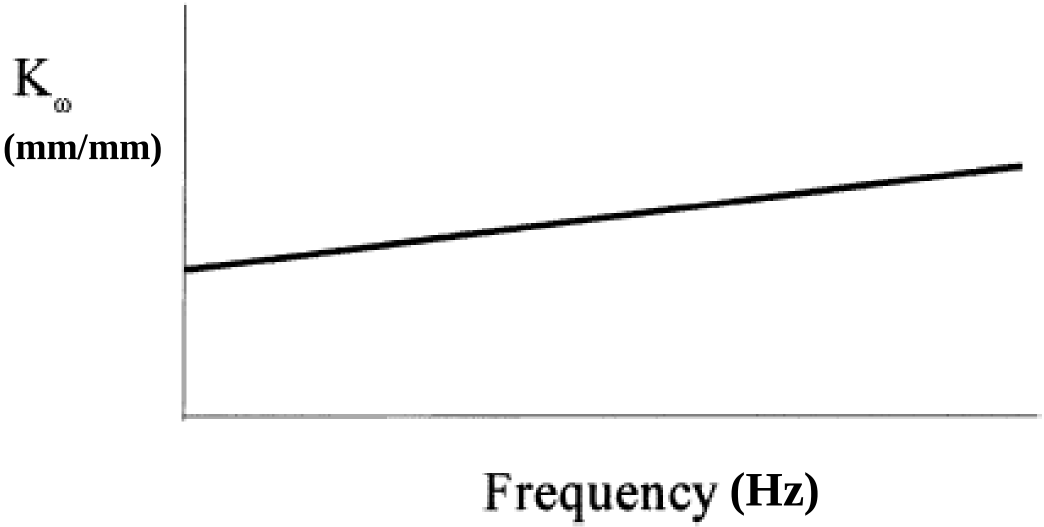

Figure 2.9: Dynamic stiffness of elastomeric mount

Source: D.A. Swanson, 1993

2.5.2 Passive Hydraulic Mounts

In 1962, Richard Rasmussen patented a hydraulic mount for increasing damping (D.A. Swanson, 1993). Two reasons can be concluded as the cause of the rising popularity of hydraulic mounts. Firstly, sophisticated mounting systems are required for the recent vehicle development trends for compact, light-weight, front wheel drive vehicles with low idle speeds. Secondly, the evolution of hydraulic mounts has turned it into highly tunable devices. An engine mount must able to satisfy two essential yet conflicting criteria which is that it must be stiff and highly damped to control the idle shake and engine mounting resonance of over the range of 5 – 30 Hz. Besides that, the engine mount should have the characteristic of a shock absorber, which is, the ability to control the motion resulting from quasi-static load conditions like travelling on bumpy roads, sudden acceleration and deceleration, cornering and braking. So to say, a submissive but lightly damped mount is needed for vibration isolation and acoustic comfort of a small amplitude excitation over a higher frequency range.

Many types of hydraulics mounts have been developed in the market currently and significant improvement in ride comfort and reduction in noise levels have been