International Journal of Future Engineering Innovations

An Evaluation of Ride Performance of Hydraulic Engine Mounting System Compared with Rubber Engine Mouting System

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Article Info
ISSN (online): 3049-1215
Volume: 02
Issue: 03
May-June 2025
Received: 01-03-2025
Accepted: 03-04-2025
Page No: 46-49

Abstract
This paper presents an evaluation of ride performance of hydraulic engine mounting system (HEMs) compared with rubber engine mounting system (REMs). To achieve this goal, a quarter-vehicle dynamic model of a passenger car under excitation source of road surface roughness is established to analyze and evaluate the ride performance of HEM compared with REM. The time domain root mean square (r.m.s) acceleration response of the vertical vehicle body (awzb) is chosen as objective function. The obtained results show that the value of the root mean square (r.m.s) acceleration responses with HEM is respectively reduced by 17% in comparison with REM when vehicle moves on ISO class B road surface at a vehicle speed of 72 km/h. In addition, the results of the study provide a theoretical basis for the development of HEMs.

DOI: https://doi.org/10.54660/IJFEI.2025.2.3.46-49

Keywords: Passenger car, hydraulic engine mount, inertia track, rubber engine mount, ride comfort

1. Introduction

HEMs are made of rubber, and they feature a hollow centre filled with hydraulic fluid, usually a glycol/water mixture. As well as supporting ICE, HEMs must absorb two main types of vibration: (i) Low frequency vibration that comes from shock excitation – accelerating or braking hard and driving on rough surfaces for example and (ii) High frequency vibration that comes from unbalanced engine forces, such as from firing pulses or any mass imbalance in the rotating or reciprocal ICE parts. Xie, J. X. *et al*. [1] proposed the engine mounting system and implement multi-objective optimization for the intrinsic frequency and the obtained results have shown that the optimized energy distribution was almost up to 90%. H. A. Tan, *et al*. [2] proposed a full-vehicle vibration model with 10 degrees of freedom under the combination of road surface roughness and ICE excitations to analyze the effect of the adding damping coefficient values into REMs on vehicle ride comfort and the obtained results have shown that the value of the adding damping coefficient has had a great impact on vehicle ride comfort. Hung, T.T., *et al*. [3] aslo proposed a full-vehicle dynamic model under the combination of two excitation sources such as ICE and road surface excitations to assess the vehicle ride comfort performance between HEMs and REMs and the obtained results have shown that the values of the root mean square (r.m.s) acceleration responses with HEMs were respectively reduced in comparison with REMs. R. Guo, et. al [4] proposed a full-vehicle dynamic model with 14 degrees of freedoms (DOFs) to to evaluate the effect of the HEM on the engine shake performance by comparing the results obtained from the known 13- DOF full-vehicle dynamic model. Similarly, Guo, R., *et al*. [5] also proposed a full vehicle model with 14 degrees of freedoms (DOFs) to calculate the engine shake, which consists of 6 of the powertrains, 1 of the fluid within the inertia track of the HEM, 3 of the car body and 4 of the unsprung mass. To improve the performance of HEM, the optimal design or damong coefficient control solutions are applied. Rasekhipour, Y. and Ohadi, A. [6] also proposed an intricate full-vehicle model to optimize the design parameters of HEMs using a global optimization method. Hoang Anh Tan, *et al*. [7] proposed a full vehicle ride dynamics model under the combination of two excitation sources such as ICE and road surface excitations to analyze three different types of Ems such as REMs, HEMs and semi-active HEMs and the obtained results have shown that the values of three objective functions with semi-active HEMs respectively reduce in comparison with REMs and HEMs when the vehicle operates under the different operating conditions. Tan, H.A., *et al.* [8] proposed a semi-active HEMs using Fuzzy Logic Controller (FLC) to analyze its ride comfort performance compared to passive HEMs using a full vehicle ride dynamics model and the obtained results have shown that the peak amplitude acceleration response values of vehicle body with semi-active HEMs respectively reduce compared to passive HEMs under the survey conditions. Li R, *et al.* [9] proposed a hierarchical fuzzy control (HFC) system for semi-active HEMs via magnetorheological (RM) fluid mounts to decrease the vertical vibration force and roll moment transmitted from an engine to a foundation. Türkücü, T. and Keleş, Ö [10] proposed new design and manufacturing aspects of MR engine mounts to validate the designed configuration of the electromagnetic coil, which controlled the MR fluid flow. The aim of this paper is to evaluate an evaluation of ride performance of HEM compared with REM using a quarter-vehicle dynamic model of a passenger car under excitation source of road surface roughness.

2. Vehicle dynamic model

2.1. Quarter-vehicle dynamic model

A quarter-vehicle dynamic model is to establish to evaluate an evaluation of ride performance of HEM compared with REM, as illustrated in Fig.1.

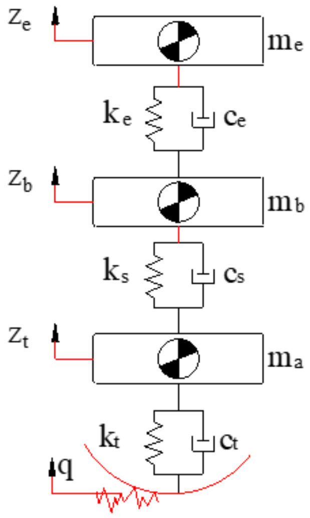

Fig 1: Quarter-vehicle dynamic model

Explanation of symbols on the model of Fig.1, me, mb and me are mass of ICE, vehicle body and vehicle axle, respectively; ke and ce are the stiffness and damping coefficients of HEM, respectively; ks and cs are the stiffness and damping coefficients of vehicle mounting system, respectively; kt and ct are the stiffness and damping coefficients of tire, respectively; ze, zb, and zt are the displacements of ICE, vehicle body and axle, respectively; q is road surface roughness.

The equations of motion of objects in Fig.1 could be written by a combined method of the multi-body system theory and D'Alembert's principle as follows.

$$\begin{cases} m_e\ddot{z}_e = -F_e \\ m_b\ddot{z}_b = F_{e2} - [k_s(z_b - z_t) + c_e(\dot{z}_b - \dot{z}_t)] \\ m_a\ddot{z}_t = [k_s(z_b - z_t) + c_e(\dot{z}_b - \dot{z}_t)] - F_t \end{cases}$$

The vertical force of the tire could be determined below

$$F_t = [k_t(z_t - q) + c_t(\dot{z}_t - \dot{q})] \quad (2)$$

Fe1 and F¬e2 are the vertical forces of HEM, will continue to be defined below

2.2. Determining vertical force of HEM

To facilitate the analysis in this study, the approximate model of the hydraulic mount with inertia track is established based on structure of HEM, as shown Fig.2. The model effective values include the inertia track fluid mass as mi=Ap2Ii, the inertia track damping as chi= Ap2Ri, the upper chamber fluid stiffness as kh1= Ap2/C1, the lower chamber fluid stiffness as kh2= Ap2/C2, the absolute displacement of the inertia track fluid mass mi as zhi.

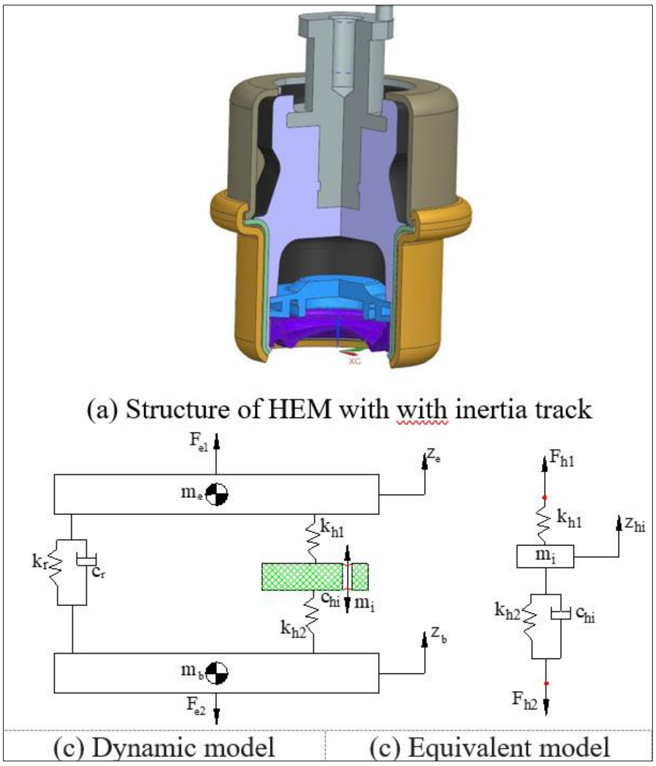

Fig 2: HEM with with inertia track

The vertical forces of REM could be determined below

$$\begin{cases} F_{e1} = F_r = k_r(z_e - z_b) + c_r(\dot{z}_e - \dot{z}_b) \\ F_{e2} = F_r = (z_e - z_b) + c_r(\dot{z}_e - \dot{z}_b) \end{cases}$$

The vertical forces of HEM could be determined below

$$\begin{cases} F_{e1} = F_r + k_{h1}(z_e - z_{hi}) \\ F_{e2} = F_r + k_{h2}(z_{hi} - z_b) + c_{hi}(\dot{z}_{hi} - \dot{z}_b) \end{cases}$$

The effective governing equation of the inertia track fluid mass mi is defined as

$$m_i\ddot{z}_{hi} = k_{h1}(z_e - z_{hi}) - k_{h2}(z_{hi} - z_b) - c_{hi}(\dot{z}_{hi} - \dot{z}_b) \quad (5)$$

2.3. Road surface excitation [8, 11, 12, 13, 14, 15, 16]: Vehicle discomfort is mainly caused by low frequency excitation sources, the road surface roughness often produces low frequency and high amplitude vibrations. In this paper, the excitation function of road surface is written according to ISO 8608 (2016) [14] which is determined by Eq. (6).

$$q(t) = \sum_{i=1}^{N} \sqrt{\frac{2 v n_0^2 G_q(n_0)}{f_{mid,i}^2} \Delta f} \cdot \cos\left(2\pi f_{mid,i} t + \varphi_i\right) \quad (6)$$

where, Gq(n0) is the coefficient of road surface roughness [14, 15] which is defined for typical road surface classes from class A to class H, n0 is a reference spatial frequency; v is vehicle speed; □i is an uniform probabilistic distribution within the 0-2π range; fmid, i is the the road roughness temporal frequencies.

3. Results and Discussion

To analyze and evaluate the ride comfort performance of HEMs compared with that of REMs, Matlab/simulink software is used to solve the equations of motion in the above section with vehicle and engine parameters in reference [3]. The simulation results of the time domain acceleration response of the vertical vehicle body (azb) when vehicle moves on ISO class B road surface at a vehicle speed of 72 km/h and full load are shown in Fig.3.

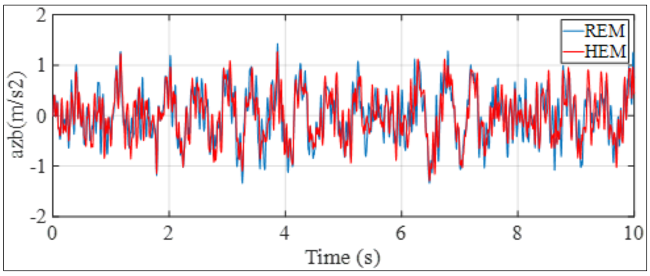

Fig 3: Time domain acceleration response of the vertical vehicle body (azb)

From the results of Fig.8, the values of the r.m.s acceleration response of the vertical vehicle body (awzb) through Eq. (7), based on the ISO 2631:1997(E) standard [16] are 0.323 m/s2 for REM, and are 0.308 m/s2 for HEMs. The awzb value with HEM reduces by 4.87 % in comparison with REM. The vehicle ride comfort performance of HEM is significantly improved in comparision with REM.

$$a_w = \left[\frac{1}{T}\int_0^T a^2(t)\,dt\right]^{\frac{1}{2}} \quad (7)$$

To verify the ride comfort performance of HEM compared to REM when the vehicle moves on the different road conditions at a vehicle speed of 72 km/h and full load, the road surface conditions such as ISO class A, ISO class B, ISO class C and ISO class D are selected to evaluate. The awzb value change with different road surface conditions is shown in Fig.4. The obtained simulation results Fig.4 shows that the awzb value with HEM reduces in comparison with REM when the vehicle moves on the different road conditions. In addition, the awb value increase very quickly when the road surface condition becomes bad.

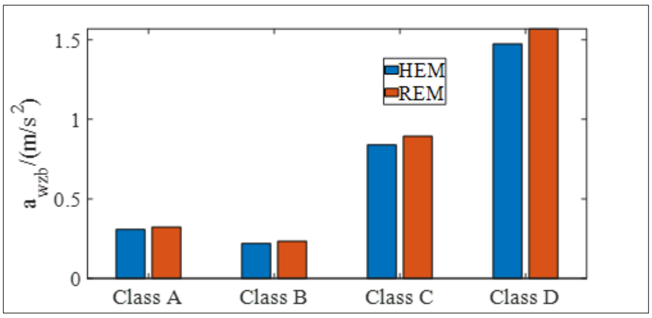

Fig 4: Awzb Value Change With Different Road Surface Conditions

4. Conclusions

In this study, a quarter-vehicle dynamic model of a passenger car under excitation source of road surface roughness was proposed to evaluate an evaluation of ride performance of HEM compared with REM. Some conclusions drawn from the obtained simulation results: (i) The vehicle ride comfort performance of HEM was significantly improved in comparision with REM, especially the awzb value with HEM was reduced by 4.87 % in comparison with REM; (ii) the awzb value with HEM was reduced in comparison with REM when the vehicle moves on the different road conditions and the awb value increase very quickly when the road surface condition becomes bad. The obtained results are the theoretical basis for the optimal design of HEM towards reducing vibrations at low frequencies.

5. Acknowledgment

The authors would like to thank the financial resources from project (Code: T2024-NCS10) in the Thai Nguyen University of Technology for supporting this work.

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