

The Fixed Points on the Nonlinear Dynamic Properties and the Parameters Identification Method for Hydraulic Engine Mount

Rang-Lin Fan

University of Science and Technology Beijing

Zhen-Hua Lu

Tsinghua University

Copyright © 2008 SAE International

ABSTRACT

Based on the third generation of hydraulic engine mounts (HEMs), which has three types of hydraulic mechanisms such as inertia track, decoupler and disturbing plate, the influences of the three different hydraulic mechanisms on the dynamic properties were studied experimentally. The working principles of the three hydraulic mechanisms and the relationship between the dynamic properties of the three generations of HEMs were revealed clearly, these experimental results will be helpful for HEM design selection. It was discovered experimentally that the frequency-dependent dynamic properties of HEM with inertia track or orifice have fixed points under different excitation displacement amplitudes. Based on the facts that the analytical results matched well with the experimental ones, a new parameter-identification-method for HEM is presented, which is clear in theory and is time- and cost-saving, the identified results were reliable.

INTRODUCTION

Powerplant vibration is the main vibration source of a vehicle. There are two important issues for powerplant vibration isolation [1–5]: one is the support function which means the large amplitude vibration at a lower frequency band should be limited and reduced rapidly. This function requires the mountings to have greater stiffness and damping. The other function is noise control, which means the mountings should effectively reduce the noise in the passenger compartment induced by small amplitude vibration of the powerplant at higher frequency bands. This function requires the mountings to have lower stiffness and damping. These two requirements are conflictive and the continuous development of mounting technology is mainly to harmonize the two conflicting requirements.

Traditional rubber mounting can not resolve the conflict because of the limitations of rubber material: its low damping can not reduce large amplitude vibration rapidly

at lower frequency bands, and so greater stiffness is needed; however, greater stiffness will result in undesired noise at higher frequency bands. On the other hand, the performance of high damping rubber is not stable and can not be widely used in the automotive industry.

At present hydraulic engine mounts (HEMs) have the best noise, vibration and harness (NVH) performance among the passive engine mounts. The HEM with an inertia track or orifice is the first generation, the one with an inertia track and decoupler is the second generation, and the one with an inertia track, decoupler and disturbing plate is the third generation [6–10]. Each new generation of HEM inherited the former's excellence and overcame the former's shortcomings in some sense.

Studies on HEM are focused on three issues.

- How to explain the working principles for three different types of hydraulic mechanisms.
- How to develop a valid lumped-parameter-model (LPM) to accurately reflect the frequency- and amplitude-variant nonlinear dynamic properties of HEMs at a wider band.
- How to obtain or identify the parameters.

These three issues are closely related. To explain the working principles correctly is the foundation for designing and developing a new HEM; a wide-band-valid LPM is a connection between the parameters and the NVH performance, and also the basis for the explanation of working principles and for parameter-sensitivity-analysis and for dynamics simulation of the whole powerplant-mounting system or the whole vehicle system; a valid LPM is always based on accurate parameters. Many studies on HEMs have been reported [1–14]; however, there are also some aspects that have not been studied or reported on, such as the ones outlined below.

(1) Generally there exist some damping-invariant fixed points in frequency-response-function (FRF) for damped vibration system. For example, there is a damping-invariant fixed point on the FRF functions of a dynamic absorber and the transmission functions of a single degree-of-freedom vibration system, when the system has different damping. HEM is a typical system with damping, so are there also any fixed points in its dynamic properties?

Singh et al. [1–3] have developed a linear LPM for the HEM with inertia track and for the HEM with inertia track and free decoupler based on whether the decoupler is or is not bottomed out. Colgate et al. [4] have also developed a linear LPM for the HEM with inertia track and a piecewise linear LPM to incorporate the decoupler behavior for the HEM with inertia track and free decoupler. Geisberger et al. [11] have developed a nonlinear LPM considering the linear and quadratic fluid damping and corresponding numerical solutions have been investigated. Patrick et al. [12] have done a large number of experimental studies on dynamic properties. However, the damping-invariant fixed points have not been discovered or reported in theory or in experimental results.

(2) The usual method to obtain the model parameters is to do some measurements on the special parts and hydraulic mechanisms such as the main rubber and the inertia track [11, 13], which requires special hydraulic test rigs and so it is time-consuming. The parameter-identification-method (PIM) is a newly studied method involving entire HEM testing that can be carried out on a general elastomer test system, which is time- and cost-saving.

This method was used first by Colgate et al. [4] based on the linear LPM, which they had developed themselves. The method assumed that the equivalent piston area of the main rubber is a known parameter. Kyprianou et al. [14] also used this method to identify the parameters for the LPM constituted of a series of highly nonlinear differential equations developed by Freudenberg.

(3) There are many studies on the dynamic properties of HEMs; however, these results are not comparable because of their difference in geometric structures. It is necessary to do quantitative comparison based on the same structure, e.g., the same main rubber, the same upper and lower chamber and the same fluid, in order to elucidate the progression and development of the dynamic properties for the three generations of HEMs and then provide a guiding principle for HEM selection and design.

Fig. 1 shows the HEM discussed in this article. Some changes of the inertia track were made, and then the influences of different hydraulic mechanisms and the length of the inertia track on the dynamic properties of the HEMs were studied experimentally to reveal the

working principles of the hydraulic mechanisms and the relationship between the three generations of HEMs. The experimental studies for HEMs with different lengths of inertia tracks revealed for the first time that the frequency-variant dynamic properties under different excitation displacement amplitudes have fixed points. Then, based on the facts that the analytical results matched well with the experimental ones, a new PIM for nonlinear LPM is presented.

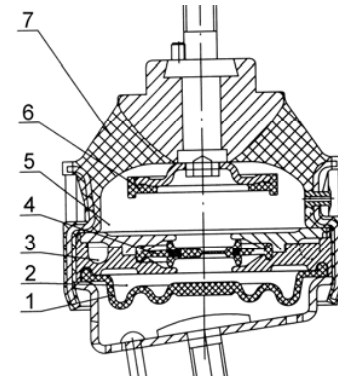


Fig. 1. The third generation of HEM. 1, Rubber bellow; 2, Lower chamber; 3, Inertia track; 4, Membrane decoupler; 5, Upper chamber; 6, Disturbing plate; 7, Main rubber.

EXPERIMENTAL STUDY

SAMPLES AND EXPERIMENTAL METHOD

The comparability of results was the basis for this experimental study of the three generations of HEMs. To assure the validity and comparability, first, the rubber and rubber-metal components for samples were manufactured on the same shift so as to assure the consistency of vulcanization process conditions; secondly, no air was allowed in chambers, because air would result in distortion and no repetition of dynamic properties; thirdly, two samples were manufactured for the same configuration of HEM. The samples and the test results were considered to be valid only if the test dynamic properties of the two samples were almost the same as each other.

A total of 12 samples as listed in Table 1 were prepared. Tests were done on an MTS 810 Elastomer Test System. Only dynamic properties in the vertical direction were tested. During testing, the mount was excited by a single frequency sinusoidal signal. Then the spectra of the test time-domain signals were analyzed and the dynamic properties, i.e., dynamic stiffness K^* (complex spring rate), dynamic stiffness modulus K , dynamic stiffness in-phase (dynamic spring rate) k , loss angle φ , dynamic stiffness out-of-phase (loss rate) k' and equivalent damping coefficient b were obtained as shown in Eq. (1) [15].

$$\begin{aligned} K^* &= K(\cos \varphi + j \sin \varphi) = k(1 + j \tan \varphi) \\ &= k + k' = k + j \omega b \end{aligned} \quad (1)$$

Table 1 Mount samples and corresponding configuration

Samples	Configuration variation relative to the HEM as shown in Fig. 1
1, 2	HEM with inertia track: the first generation, without the disturbing plate, the decoupler being fixed, the length of inertia track is its original length $l_{i1} = 216.59$ mm
3, 4	HEM with inertia track and decoupler: the second generation, without disturbing plate
5, 6	HEM with inertia track and decoupler and disturbing plate: the third generation shown in Fig. 1
7, 8	Main rubber mount, without inertia track and decoupler and disturbing plate, no filled liquid
9, 10	HEM with inertia track whose length is $l_{i2} = 121.29$ mm, the other configurations are the same as Samples 1 and 2
11, 12	HEM with inertia track whose length is $l_{i3} = 75.81$ mm, the other configurations are the same as Samples 1 and 2

COMPARISON BETWEEN THE DYNAMIC PROPERTIES OF THE THREE GENERATIONS OF HEMS AND THE RUBBER MOUNT

The static force-displacement properties of two samples (samples 7 and 8 listed in Table 1) for the main rubber were almost the same [16]. In fact, the static properties of all samples were consistent. These results show that the vulcanization process conditions were stable and consistent, and the static properties of the HEMs were determined only by their main rubber. The test average static stiffness of the main rubber between a compression load of 400 - 600 N was $k_{rs} = 149.72$ N/mm.

The comparison between the dynamic properties of the two samples with the same configuration shows that the dynamic properties under lower frequency band, larger amplitude excitation (Case 1) and higher frequency band, smaller amplitude excitation (Case 2) were also almost the same, which means that the mount assemblies and their components were consistent. This allowed us to study the influence of the three different hydraulic mechanisms, i.e. inertia track, decoupler and disturbing plate, on the dynamic properties of the HEMs based on their dynamic differences and then reveal their working principles. To make the curves clear and legible in the following figures, only one sample's test results are shown.

The lower frequency band and higher frequency band dynamic properties of the main rubber, HEM with inertia track (first generation), HEM with inertia track and decoupler (second generation) and HEM with inertia track, decoupler and disturbing plate (third generation) are shown in Fig. 2, which clearly shows the progression and development of their dynamic properties.

Main rubber mount

As shown by curves 19 and 20 in Fig. 2, the dynamic stiffness modulus K_r and dynamic stiffness in-phase k_r under Cases 1 and 2 followed an almost continuously horizontal line; thus it can be considered as a constant. The average values from all test points of the two

samples under Cases 1 and 2 were $K_r = 225.17$ N/mm (the standard deviation was 13.66 N/mm), $k_r = 217.84$ N/mm (the standard deviation was 9.15 N/mm). The dynamic-static ratio of the main rubber mount was $R_{ds} = 1.46$.

The loss angle under two cases was a continuous bias, whereas the damping coefficient b_r in the vertical direction was also a continuously horizontal line (the curve is not shown in Fig. 2) and can be considered as a constant too. As with the former averaging method, the average value was $b_r = 80.4 \times 10^{-3}$ N-s/mm (the standard deviation was 9.5×10^{-3} N-s/mm).

HEM with inertia track

As shown by curves 1 - 4 in Fig. 2, its dynamic properties under different large amplitude excitation at lower frequency bands is drastically frequency- and amplitude-variant. As the frequency increased, the lowest and peak value appeared consequently on its dynamic stiffness modulus and dynamic stiffness in-phase, and then tended to become a horizontal line; the peak loss angle decreased as excitation amplitude increased; however it was far larger than the one of the main rubber mount. This is the very embodiment of the larger damping of the HEM.

Under different small amplitude excitation at higher frequency bands, the dynamic stiffness modulus K_∞ and dynamic stiffness in-phase k_∞ (curves 5 and 6 in Figs. 2(a) and 2(b)) were almost superposed and tended to be a horizontal line, so this HEM was also considered as amplitude-invariant and constant. The average values from the test points of the two samples between 50 and 200 Hz were $K_\infty = 564.08$ N/mm (the standard deviation was 9.65 N/mm), $k_\infty = 540.09$ N/mm (standard deviation 13.45 N/mm). The ratio of K_∞ and K_r , i.e., the dynamic-hardening-coefficient of the HEM was $R_d = 2.51$. Its loss angle (curves 5 and 6 in Fig. 2(c)) was also superposed and tended to be superposed with curve 20 of the main rubber mount. This phenomenon indicated that the damping effect of the inertia track had disappeared at a higher frequency band and the damping of the HEM with