Optimal Switching Parameter Control of Semi-Active Engine Mount

Thanh Quoc Truong**, Young Kong Ahn*, Kyoung Kwan AHN**,

* ReMM, University of Ulsan, Korea (Tel: +82-52-259-1501; Email: ahn@mail1.pku.ac.kr)
** School of Mechanical & Automotive Engineering, University of Ulsan, Korea (Tel: +82-52-259-2282; Email: kkahn@ulsan.ac.kr)

Abstract

This paper describes work on isolation of vibration related engine by a hydraulic engine mount with controllable area of inertia track. Automotive engine mounts are required to constrain motion of engine shake resulting from low-frequency road input of shock excitation and also to isolate noise and vibration generated by the engine with unbalanced disturbance. Vibration frequency of engine shake is low and vibration amplitude is large, while vibration frequency of unbalanced vibration of engine is high and vibration amplitude is small. High damping and stiffness are needed to reduce the vibration of the engine shake, but low damping and stiffness are required to reduce the noise and unbalanced vibration [1-3].

Damping of a conventional rubber is enough to isolated engine shake. Increasing damping increase noise and vibration in high frequency range. Therefore, hydraulic mounts with inertia track are developed to increase damping in low frequency range and to reduce unbalanced vibration [4-7]. However, the hydraulic mounts have resonance peak created by fluid flow. To reduce the resonance peak, decoupler is inserted in the hydraulic mount.

On the other hand, semi-active and active hydraulic mount have been developed to increase performance of the passive hydraulic mount [9-10]. Since semi-active mounts have more simple structures and lower electric power and lower cost to make the mounts, many researches works on semi-active mounts.

In the paper, a new hydraulic mount with controllable area of the inertia track is proposed. The design parameter of area inertia track in the hydraulic mount is the most sensitivity for performance of the mount. When the area of the inertia track is changed, volumetric stiffness is greatly changed.

The obtained results from numerical simulation show that the transmissibility of the mount is greatly reduced by tuning the area of the inertia track.

Keywords: Engine mount; Hydraulic mount; Vibration isolation; semi-active vibration control

1. INTRODUCTION

Automotive engine mount are require to constrain motion of engine shake resulting from shock excitation and also to isolate noise and vibration generated by the engine with unbalanced disturbance. Vibration frequency of engine shake is low and vibration amplitude is large, while vibration frequency of unbalanced vibration of engine is high and vibration amplitude is small. High damping and stiffness are needed to reduce the vibration of the engine shake, but low damping and stiffness are required to reduce the noise and unbalanced vibration [1-3].

Damping of a conventional rubber is enough to isolated engine shake. Increasing damping increase noise and vibration in high frequency range. Therefore, hydraulic mounts with inertia track are developed to increase damping in low frequency range and to reduce unbalanced vibration [4-7]. However, the hydraulic mounts have resonance peak created by fluid flow. To reduce the resonance peak, decoupler is inserted in the hydraulic mount.

On the other hand, semi-active and active hydraulic mount have been developed to increase performance of the passive hydraulic mount [9-10]. Since semi-active mounts have more simple structures and lower electric power and lower cost to make the mounts, many researches works on semi-active mounts.

In the paper, a new hydraulic mount with controllable area of the inertia track is proposed. The design parameter of area inertia track in the hydraulic mount is the most sensitivity for performance of the mount. When the area of the inertia track is changed, volumetric stiffness is greatly changed.

The obtained results from numerical simulation show that the transmissibility of the mount is greatly reduced by tuning the area of the inertia track.

2. MATHEMATICAL MODEL OF HYDRAULIC MOUNT WITH CONTROLLABLE AREA OF THE INERTIA TRACK

Physical description of Semi-active hydraulic engine mount is showed as Fig. 1. The mount consists of a rubber structure contain two fluid chambers: upper chamber (main chamber), lower chamber (compression chamber) and controllable area of inertia track which controlled by a servo motor.

Mathematical model of the hydraulic mount is considered such as Fig. 2. The hydraulic and mechanical model can be transferred to mechanical mode shown in Fig. 3. When the area of the inertia track changed, the fluid does not flow in the inertia track. Therefore, the model of the mount is changed from the model of Figs. 3-4. The volumetric damping of chamber is neglected (assumed $B_u = 0$ and $B_l = 0$).
The transmitted forces, $F_i$, of the opened and closed inertia track models can be obtained as shown in Figs. 3-4 and from Eqs. (3) - (4).

$$F_{i,o} = (K_x + K_y + R_y)X - K_y \frac{A_i}{A_p} X_i$$  \hspace{1cm} (5)

$$F_{i,c} = (K_x + K_y + R_y)X$$  \hspace{1cm} (6)

where

$$X_i = K_y \left( \frac{A_i}{A_p} \right) M_i s^2 + C_i s + (K_y + K_z)(A_i / A_p)^2$$

From Eqs. (5)-(6), the dynamic stiffness, $K''$, for the opened and closed inertia track models can be obtained as follows,

$$K''_{o} = K''_{o} + jK''_{o} = \frac{F_{i,o}}{X}$$  \hspace{1cm} (7)

$$K''_{c} = K''_{c} + jK''_{c} = \frac{F_{i,c}}{X}$$  \hspace{1cm} (8)

The real part $K'$ of the dynamic stiffness $K''$ represents the stiffness property of the mount, and imaginary part, $K''$ which indicates its damping property can be obtained from Eqs. (7) - (8).

$$K'_{o} = K_x + K_y - \frac{K'^2}{E^2 + (C \omega)^2}$$  \hspace{1cm} (9)

$$K'_{c} = K_x + K_y$$  \hspace{1cm} (10)

$$K'' = K_x + K_y$$  \hspace{1cm} (11)

where

$$E = (K_y + K_z)(A_i / A_p)^2 - M_i \omega^2$$

Transmissibility $T_F$ for unbalanced vibration the engine and relative transmissibility $T_{RD}$ for engine shake are useful in assessing the isolation effectiveness of the mount and can be obtained from the dynamic stiffness or the real and imaginary parts of the dynamic stiffness.

$$T_{RD} = \frac{X - Y}{Y} = \frac{-M_s^2}{M^2 + K'}$$  \hspace{1cm} (13)

$$T_{RD} = \frac{M \omega^2}{\sqrt{(K' - M \omega^2)^2 + K''^2}}$$

$$T_F = \frac{X}{Y} = \frac{K'_o}{M^2 + K'}$$  \hspace{1cm} (14)

3. NUMERICAL SIMULATION RESULTS

The derived equations in the second chapter are used in this simulation with the mount parameter listed in Table 1. Figs. 5-7 obtained from the simulation shows frequency responses of the mount according to the variation of the
area of inertia track. In the figures, 100 % means to original area of inertial track of hydraulic mount. When the area increases, the notch and resonant frequency by fluid flow increases as shown in Fig. 5 and resonant peak decreases. When the area is closed and almost closed, resonant frequency is one as shown in Figs 6-7. Furthermore, two resonant frequencies appear according to increasing the area and amplitude of the first resonant peak increases but amplitude of the second resonant peak decreases. When the area is tuned to find optimal area according to the excitation frequency, the transmissibility is greatly reduced as shown in Fig. 8 and the tuned area is shown in Fig. 9. The area is changed from 1-150%

### 4. CONTROL SYSTEM

The hydraulic engine mount control system consist a servo motor to adjust area of inertia track, a sensor monitors frequency of engine and send signal to controller, an optimal switching parameter controller receives signal to control servo motor, a PID controller monitors the position of area track. The Figs. 10-11 show a conceptual diagram of the semi-active engine mount system. The area of inertial track is controlled by servo-motor, at each motor position has resolution 1 percent and control range of 150 percent.

### 5. CONCLUSION

In this paper, a new hydraulic engine mount with the controllable area of the inertia track is proposed. The motion equation derived from the mechanical model of the mount is used in numerical simulation. The resonant peak, notch and resonant frequencies changed according to the variation of the area of the inertia track. When the area is tuned, the transmissibility of the mount is greatly reduced.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Original value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_p )</td>
<td>( 2.5 \times 10^{-3} ) m²</td>
</tr>
<tr>
<td>( A_i )</td>
<td>( 5.72 \times 10^{-5} ) m²</td>
</tr>
<tr>
<td>( I_i )</td>
<td>( 3.81 \times 10^{-5} ) N·s²/m²</td>
</tr>
<tr>
<td>( L_i )</td>
<td>( 212 \times 10^{-3} ) m</td>
</tr>
<tr>
<td>( \rho )</td>
<td>( 1.028 \times 10^{3} ) kg/m³</td>
</tr>
<tr>
<td>( R_i )</td>
<td>( 1.05 \times 10^{7} ) N·s/m</td>
</tr>
<tr>
<td>( C_i = 1/K_i )</td>
<td>( 3.0 \times 10^{-11} ) m³/N</td>
</tr>
<tr>
<td>( C_i = 1/K_i )</td>
<td>( 2.6 \times 10^{-9} ) m³/N</td>
</tr>
<tr>
<td>( K_r )</td>
<td>( 2.25 \times 10^{5} ) N/m</td>
</tr>
<tr>
<td>( R_r )</td>
<td>100 N·s/m</td>
</tr>
<tr>
<td>( M )</td>
<td>62 kg</td>
</tr>
</tbody>
</table>
Fig. 10 Flow chart of controller

START

Vibration Signal input

Frequency Identifier

Selection of Optimal Opening Area of Inertia track

Control of Opening Area of Inertia Track

N

Stop ?

Y

END

Fig. 10 Block of control opening Area of Inertia Track

 NOMENCLATURE

\( A_p \) : Effective piston area

\( A_i \) : Average cross-sectional area of the inertia track

\( B_{vt} \) : Volumetric damping in the top chamber (= 0)

\( B_{vb} \) : Volumetric damping in the bottom chamber (= 0)

\( R_r \) : Rubber damping coefficient in the top chamber

\( R_i \) : Resistance in the inertia track

\( C_1 \) : Compliance in the top chamber

\( C_2 \) : Compliance in the bottom chamber

\( C_i \) : Viscous damping coefficient in the inertia track

\( (A_i^2R_i) \)

\( F_{in, O} \) : Input force with opened inertia track

\( F_{t, O} \) : Transmitted force with opened inertia track

\( F_{in, C} \) : Input force with closed inertia track

\( F_{t, C} \) : Transmitted force with closed inertia track

\( \rho \) : Density of fluid

\( s \) : The Laplace operator.

\( \omega \) : Vibration frequency

\( T_{F} \) : Transmissibility

\( T_{RD} \) : Relative transmissibility

\( x_e \) : Displacement of mass of an engine

\( x_i \) : Displacement of fluid flow mass in the inertia track

REFERENCES


[9] Toshiyuki Shibayama et. al., Active engine mount for a large amplitude of idling vibration, *SAE* 951298


