한국소음진동공학회 2010년 추계학술대회논문집, pp.473~474

Development of Active Engine Mount of an Automobile with Variable Cylinder Management Technology

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1. Introduction

As the quality of automobile improves, customers demand more comfortable and efficient vehicles. Variable Cylinder Management (VCM) is among the best fuel saving technology introduced in the 21^{st} century. It deactivates 1/3 or 1/2 of cylinders according to the driving conditions and is usually applied in the six or eight cylinder engine. When operating in 3-cylinder mode, engine vibration is reduced by extrapolating vibration from the change in crank shaft rotation speed and sending the information to the active control engine mount, which compresses/extends an actuator in same phase, same period motion to dampen the engine mount.

Several kinds of engine mounting systems from elastomeric to hydraulic and from passive to active have been developed by many researchers such as R.Rasmussen, G.Kim, R.Singh, P.L.Graph, T.Duclos, J.H.Kim, S.Ushijima, B.H.Lee, and many more. This paper deals with the active engine mount which is equipped with high speed actuators with operating bandwidths matching the disturbance spectrum. In section 2 dynamic modeling has been explained. In section 3 proposed algorithms for maintaining the vibration characteristics, when one bank of cylinders is deactivated, has been explained. Desired vibration characteristics can be analyzed by simulation results.

2. Dynamic Modeling of Engine and Chassis

2.1 Equation of Motions

A rigid body in the space has six degrees of freedom as shown in figure.1. For the dynamic model of engine and chassis, the kinetic, potential and dissipation energies can be found as;

$$K = \frac{1}{2}m\dot{z}^2 + \frac{1}{2}J_P\dot{\gamma}^2 + \frac{1}{2}J_Q\dot{\beta}^2 + \frac{1}{2}m\dot{x}^2 + \frac{1}{2}m\dot{y}^2 + \frac{1}{2}J_R\dot{\alpha}^2$$

$$U = \frac{1}{2}\sum_{i=1}^{3}\sum_{j=1}^{3}\left(k_{Rij}\xi_{Ri}\xi_{Rj} + k_{Lij}\xi_{Li}\xi_{Lj} + k_{Tij}\xi_{Ti}\xi_{Tj}\right) \quad 1$$

$$W = \frac{1}{2}\sum_{i=1}^{3}\sum_{j=1}^{3}\left(c_{Rij}\dot{\xi}_{Ri}\dot{\xi}_{Rj} + c_{Lij}\dot{\xi}_{Li}\dot{\xi}_{Lj} + c_{Tij}\dot{\xi}_{Ti}\dot{\xi}_{Tj}\right)$$

Using Lagrange's equation

$$\frac{d}{dt}\left(\frac{\partial K_1}{\partial \dot{\eta}_i}\right) + \frac{\partial U_1}{\partial \eta_i} + \frac{\partial W_1}{\partial \dot{\eta}_i} = q_i \quad , i = 1, 2, \ldots$$

The equations of motion for engine and chassis are;

$$[M_1]\{\ddot{\eta}_1\} + [C_1]\{\dot{\eta}_1\} - [C_2]\{\dot{\eta}_2\} + [K_1]\{\eta_1\} - [K_2]\{\eta_2\} = \{q_1\}$$

$$[M_2]\{\ddot{\eta}_2\} + ([C_2]+[C_3])\{\dot{\eta}_2\} - [C_1]\{\dot{\eta}_1\} + ([K_2]+[K_3])\{\eta_2\} - [K_1]\{\eta_1\} = \{q_2\} \quad 2$$

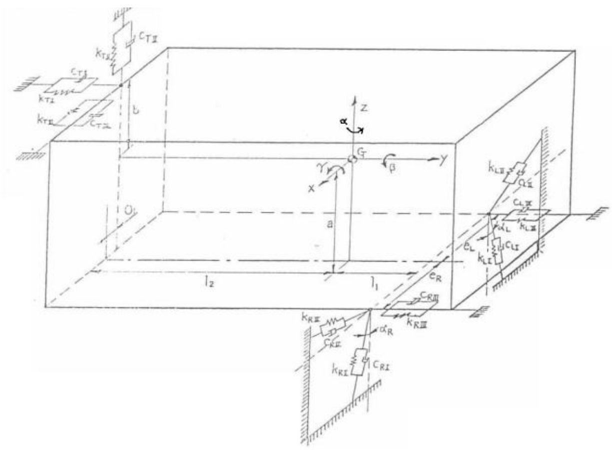

Fig. 1 Dynamic model of engine

3. Proposed Algorithm and Simulation

3.1 Proposed Adaptive Algorithm

Figure 2 shows the proposed algorithm for maintaining the vibration characteristics unchanged during the mode change i.e. from 6 to 3 cylinders.

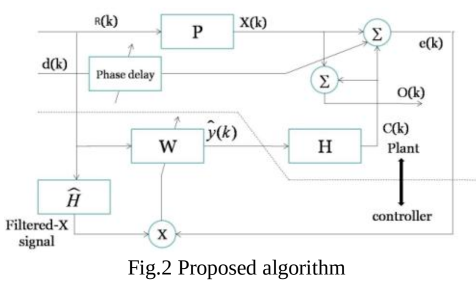

Fig.2 Proposed algorithm

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$$e(k) = X(k) - C(k) - d(k) = O(k) - d(k) \qquad 3$$

When error goes to zero, desired signal *d (k)* becomes equal to *O (k)*, so we can have desired vibration characteristics.
In order to achieve our goal we have defined a cost function such as;

$$J = e_x^2 + e_y^2 + e_z^2 + e_{\alpha x}^2 + e_{\alpha y}^2 + e_{\alpha z}^2 \qquad 4$$

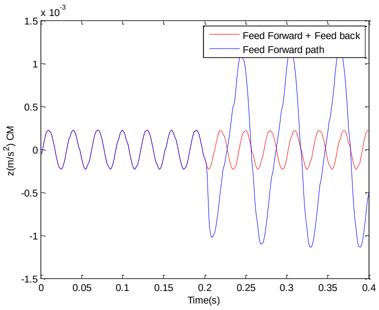
Where error is the difference between actual and measured accelerations. Finally, we have the updated function for adaptive filter.

$$\begin{aligned} W_1(k+1) &= W_1(k) - \mu_1 \frac{\partial J(k)}{\partial W_1(k)} \\ &= W_1(k) + 2\mu_1 \left(-e_x \frac{z_1 l_a}{J_y} + e_z \left(\frac{1}{M} + \frac{x_1 l_a}{J_y} \right) - e_{\alpha y} \frac{l_a}{J_y} \right) R(k) \qquad 5 \\ W_2(k+1) &= W_2(k) - \mu_2 \frac{\partial J(k)}{\partial W_2(k)} \\ &= W_2(k) + 2\mu_2 \left(-e_x \frac{z_1 l_b}{J_y} + e_z \left(\frac{1}{M} + \frac{x_1 l_b}{J_y} \right) - e_{\alpha y} \frac{l_b}{J_y} \right) R(k) \end{aligned}$$

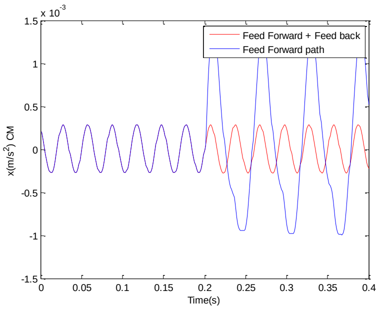
Here it is worthy to mention that we consider the motion control at the centre of mass which is the most general case.

3.2 Simulation results

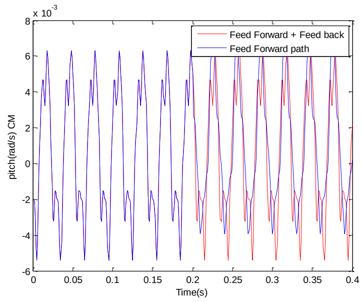
The input which is used in the simulation is same as equation 2.The vehicle is driven on a constant speed of 2000 rpm. Simulation frequency is about 33.3 Hz and 10 weighting coefficients are considered for FIR filter. The sampling time is taken as 1msec and actuator dynamics is not considered means (H=1).



(a) Heave motion

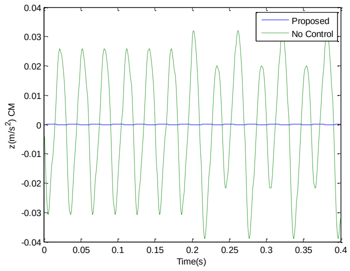


(b) Longitudinal motion

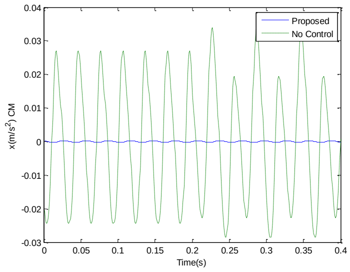


(c)Pitch motion

Fig 3 Comparison of Open and Open+ Feed forward
From 0.2-0.4 sec only 3 cylinders are working



(a) Heave motion



(b) Longitudinal motion

Fig. 4 Comparisons of control and no control

Figure 3 shows, when we apply the feed forward path, the amplitude is high, though the trend is similar so by applying the proposed algorithm (feed forward + feedback path) we have the same vibration characteristics when we deactivate the 3 cylinders. Figure 4 shows the vibration characteristics are not stable when there is a shift of mode in the case of no control; however by applying the proposed algorithm we have the desired results.

4. Conclusions

Novel adaptive algorithm is proposed to maintain the vibration characteristics during the engine mode change from 6 to 3 cylinders, based on the conventional Fx-LMS algorithm. The simulation confirms the feasibility of the proposed algorithm.

Acknowledgement

I would like to express sincere gratitude towards my advisors, also to give thanks to my lab members and Mr.K.T.Kim for their kind help during this study.