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Effect of Internal Combustion Engine Vibrations on Vehicle Ride Comfort

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ABSTRACT: Vibrating excitation source of internal combustion engine not only affects vehicle noise but also affects vehicle ride comfort. In order to evaluate their effect on vehicle ride comfort, a full-vehicle dynamic modelunder the combination of two excitation sources such as internal combustion engine and road surface excitationsis established.The time domain acceleration responses of the vertical motion, pitch and roll angles of vehicle body are chosen as objective functions to evaluate the influence of vibrating excitation sources on vehicle ride comfort. The obtained results indicate that the vibrating excitation sources have a significant the influence on vehicle ride comfort

KEYWORDS: Internal combustion engine (ICE),Vibrating excitation sources(VES), Full-vehicle dynamic model, Ride comfort.

I. INTRODUCTION

Vibrating excitation source of internal combustion engine not only affects vehicle noise but also affects vehicle ride comfort.The combination of road surface roughness and vibrating excitation sources of internal combustion engine (ICE)were proposedto evaluate the effect of the adding damping coefficient values into the rubber mounting system on vehicle ride comfort [1]. The vibrating excitation sources of internal combustion engine (ICE) wereonly consideredto evaluate the effect of the hydraulic engine mounts (HEMs)on the engine shake performance [2].Similarly,the vibrating excitation sources of internal combustion engine (ICE)were proposedto evaluate the vehicle ride comfort performance between the hydraulic engine mount system (HEMs) and rubber engine mount system (REMs) [3]. A full-vehicle dynamic model with 10 degree of freedoms was proposed to investigate the effect of internal combustion engine vibrations on vehicle ride comfort which was analyzed based on the value of the root mean square (RMS) of accelerationresponses of the vertical, pitch, and roll vibrationsof vehicle body according to the international standard ISO 2631-1 [4]. A dynamic model of automobiles with a 4WD transmission system was proposed to evaluate the effect of internal combustion engine torque such cylinder number and engine throttle level on the ride comfort of automobile [5].Engine produces the vibratory forces due to the unbalanced forces from the engine parts during the operation. The vibration caused by the engine at the supports is torsional vibration and the longitudinal vibration. The torsional vibration is caused at the crankshaft due to the fluctuating engine combustion pressures and engine loads. The longitudinal vibrations are caused at the block and the mounts by the reciprocating and rotating parts of the engine.A review was structured as engine multibody modeling, engine vibrations and engine mounting areas and revealed the gaps and untouched parts that requires further research [6].

The main purpose of this study is to propose evaluate the influence of vibrating excitation sources on vehicle ride comfort. A full-vehicle dynamic modelunder the combination of two excitation sources such as internal combustion engine and road surface excitationsis established. The time domain acceleration responses of the vertical motion, pitch and roll angles of vehicle body are chosen as objective functions to evaluate the influence of vibrating excitation sources on vehicle ride comfort.

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II. FULL-VEHICLE DYNAMIC MODEL

In order to evaluate the influence of vibrating excitation sources on vehicle ride comfort, a full-vehicle dynamic model is established under the combination of two excitation sources such as the internal combustion engine and road surface excitations, as shown in Fig.1. In Fig. 1,$k_{ei}$are the stiffnesscoefficients ofthe passive hydraulic engine mounting system, $c_{ei}$are damping coefficients of the passive hydraulic engine mounting system; k_{ij} are the stiffnesscoefficients ofvehicle suspension system; c_{nj} are the damping coefficients ofvehicle suspension system; k_{tnj} are the stiffnesscoefficients oftires; $c_{tnj}$are the damping coefficients oftires; z_b, φ_b, $\theta_b$are the vertical and angular displacements of vehicle body; z_e, φ_e, $\theta_e$are the vertical and angular displacements of engine body; $q_{ij}$are the road surface excitations; a, b, B_t and B_s are the distances; m_{nj} và m_b are the mass of axles and vehicle body; $m_e$is mass of engine (i=1,2,3,4 và n=1-2; j=r,l); (x_1,y_1); (x_2,y_2); (x_3,y_3) ; (x_4,y_4) are the coordinates of the force points of the four engine supports in the coordinate system via XYZ; (x_{e1},y_{e1}); (x_{e2},y_{e2}); (x_{e3},y_{e3}) ; (x_{e4},y_{e4}) are the coordinates of the force points of the four engine supports in the coordinate system via $X_eY_eZ_e$

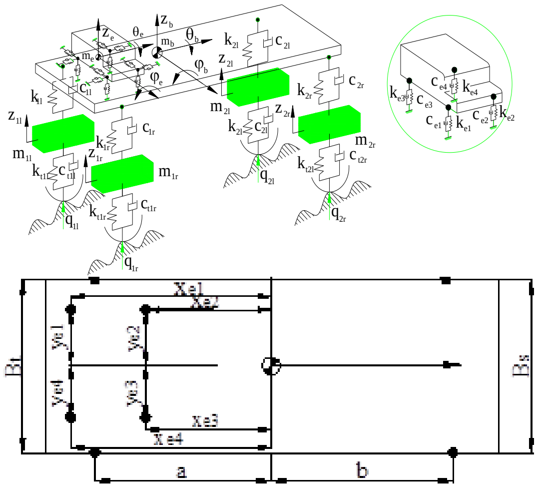

Figure 1. Full-vehicle dynamic model[8,9]

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

$$m\ddot{z}_{1l} = k_{1l}\left(z_{b1l} - z_{1l}\right) + c_{1l}\left(\dot{z}_{b1l} - \dot{z}_{1l}\right) \quad (1)$$
$$-k_{t1l}\left(z_{1l} - q_{1l}\right) + c_{t1l}\left(\dot{z}_{1l} - \dot{q}_{1l}\right)$$

$$m\ddot{z}_{1r} = k_{1r}\left(z_{b1r} - z_{1r}\right) + c_{1r}\left(\dot{z}_{b1r} - \dot{z}_{1r}\right) \quad (2)$$
$$-k_{t1r}\left(z_{1r} - q_{1r}\right) + c_{t1r}\left(\dot{z}_{1r} - \dot{q}_{1r}\right)$$

$$m\ddot{z}_{2l} = k_{2l}\left(z_{b2l} - z_{2l}\right) + c_{2l}\left(\dot{z}_{b2l} - \dot{z}_{2l}\right) \quad (3)$$
$$-k_{t2l}\left(z_{2l} - q_{2l}\right) + c_{t2l}\left(\dot{z}_{2l} - \dot{q}_{2l}\right)$$

$$m\ddot{z}_{2r} = k_{2r}\left(z_{b2r} - z_{2r}\right) + c_{2r}\left(\dot{z}_{b2r} - \dot{z}_{2r}\right) \quad (4)$$
$$-k_{t2r}\left(z_{2r} - q_{2r}\right) + c_{t2r}\left(\dot{z}_{2r} - \dot{q}_{2r}\right)$$

$$m_b\ddot{z}_b = (F_{e1} + F_{e2} + F_{e3} + F_{e4}) \quad (5)$$
$$-(F_{1r} + F_{1l} + F_{2l} + F_{2r})$$

$$I_y\ddot{\varphi}_b = (F_{1r} + F_{1l}).a - (F_{2r} + F_{2l}).b \quad (6)$$
$$-(F_{e1}.x_1 + F_{e2}.x_2 + F_{e3}.x_3 + F_{e4}.x_4)$$

$$I_x\ddot{\theta}_b = F_{1l}.\frac{B_t}{2} + F_{2r}.\frac{B_s}{2} - F_{1r}.\frac{B_t}{2} - F_{2l}.\frac{B_s}{2} \quad (7)$$
$$+(F_{e1}.y_1 + F_{e2}.y_2) - (F_{e3}.y_3 + F_{e4}.y_4)$$

$$m_e\ddot{z}_e = F_z - \left(F_{e1} + F_{e2} + F_{e3} + F_{e4}\right) \quad (8)$$

$$I_{ey}\ddot{\varphi}_e = M_y + F_{e1}.x_{e1} + F_{e4}.x_{e4} \quad (9)$$
$$-F_{e2}.x_{e2} - F_{e3}.x_{e2}$$

$$I_{ex}\ddot{\theta}_e = M_x + F_{e3}.y_{ee} + F_{e4}.y_{e4} \quad (10)$$
$$-F_{e1}.y_{e1} - F_{e2}.y_{e2}$$

Road surface excitation[3]:In this study, the filtering white noise method is used to describe the time domain excitation of the road surface based on reference [3] and time domain representation of the road surface can be given

$$\dot{q}(t) + 2\pi f_0 q(t) = 2\pi n_0 \sqrt{G_q(n_0)}vw(t) \quad (11)$$

where, $G_q(n_0)$ is the road roughness coefficient which is defined for typical road classes from A (very good) to H (very poor) according to ISO 8068(1995) [7], v=f/n is the speed of vehicle from 10 m/s to 30 m/s, n is the road space frequency from 0.013 m^{-1} to 3.33 m^{-1}, and it can guarantee the temporal frequency of road surface f ranges from 0.33 Hz to 28.3 Hz which is the low excitation frequencies of road surfacetransmitted to vehicle body; f_0 is a minimal boundary frequency with a value of 0.0628 Hz;n_0 isareference spatial frequency which is equal to 0.1 m; w(t) is a whitenoise signal.

ICEvibrating excitation sources[3, 6]: In this study, the vertical inertia excitation force due to the reciprocating mass of engine, the roll and pitch excitation moments of engine with a 4-stroke in-line engine are defined as

$$F_{ez} = 4m_p r\lambda\omega^2\cos(2\omega t) = 4m_p r\lambda\omega^2\cos(2\pi ft) \quad (12)$$

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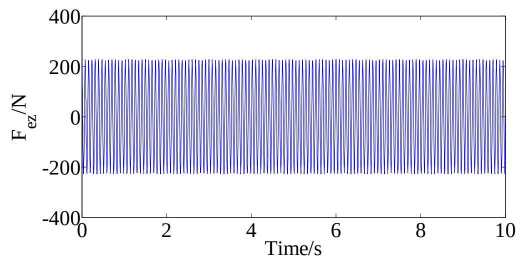
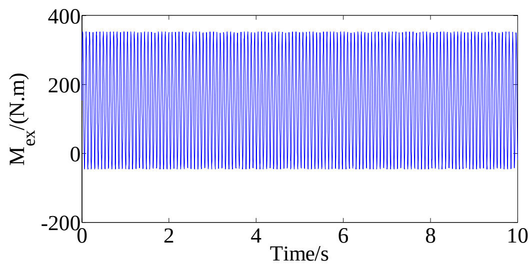
$$M_{ex} = M_e\left[1+1.3\sin(2\omega t)\right] = M_e\left[1+1.3\sin(2\pi ft)\right] \quad (13)$$

$$M_{ey} = 4m_p r\lambda\omega^2 l_r \cos(2\omega t) = 4m_p r\lambda\omega^2 l_r \,\mathrm{co} \quad (14)$$

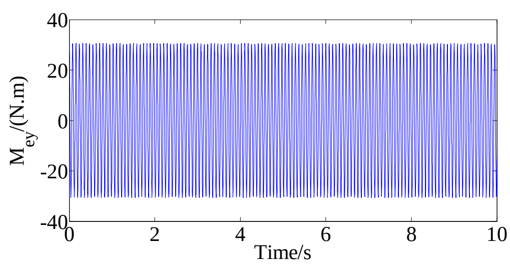
where, $\omega=2\pi f$ is the angular velocity of crank shaft, $f= n_e/60$ is the excitation engine frequency, n_e is the engine speed, m_p is the pistonmass, M_e is mean value of ICE torque $M_e= -6.810^{-6}n_e^2 + 0.059n_e + 112.5$ N.m, r is the rotational radius of crank arm, λ is the ratio of r to the length of the shaft, l_r isthe distance between the CG and the centre-line of the second and third cylinders.
The vertical inertia excitation force due to the reciprocating mass of engine Eq.(12), the roll and pitch excitation moments of engine Eq.(13) and Eq.(14) are simulated by Matlab/Simulink software and the simulation results with m_p=0.702kg, r=0.044m, λ=0.29, l_r= 0.135m, n_e=760rpm [3] are shown in Figure 2.



(a) Vertical inertia excitation force of engine



(b) Roll excitation moment of engine

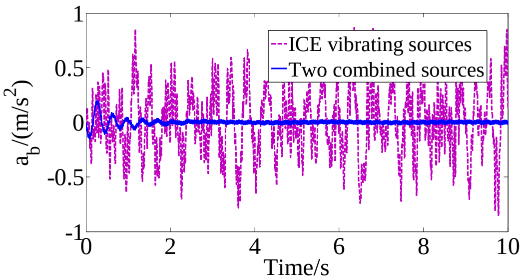


(c) Pitch excitation moment of engine

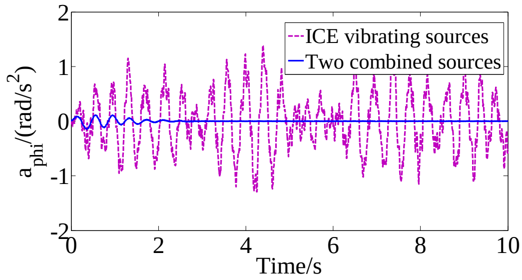
Figure 2. Vertical inertia excitation force, roll and pitch excitation moments of engine[3]

III. RESULTS AND ANALYSIS

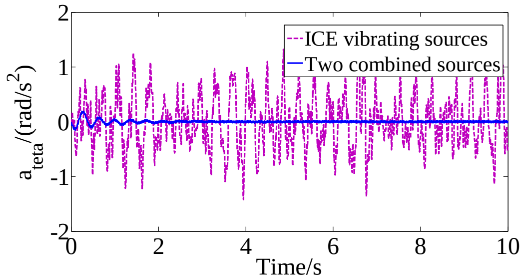
In order toevaluate the influence of vibrating excitation sources on vehicle ride comfort, Matlab/simulink software is used to solve the equations of motion in the above section with vehicle and engine parameters in references [9]. The simulation results of the time domain acceleration responses of the vertical motion (a_b), pitch and roll angles (a_{phi} and a_{teta}) of vehicle bodywhen the vehicle moves on ISO class B surfaces road condition and ICE engine operates at the speed of 1680prm (vehicle speed of 72 km/h) and whenICE engine operates at the speed of 1680prm (vehicle speed of 0 km/h).From the achieved results in Fig.3, we show that the peak amplitude values of a_b, $a_{phi}$and a_{teta} with ICE vibrating sources respectively increase in comparison without ICE vibrating sourceswhich indicates that ICE vibrating sources have a significant effect on vehicle ride comfort.



(a) Vertical motion of vehicle body



(b) Pitch angle of vehicle body



(c) Roll angle of vehicle body

Figure 3. The simulation results of the time domain acceleration responses of the vertical motion (a_b), pitch and roll angles (a_{phi} and a_{teta}) of vehicle bodywhen the vehicle moves on ISO class B surfaces road condition and ICE engine operates at the speed of 1680prm (vehicle speed of 72 km/h)

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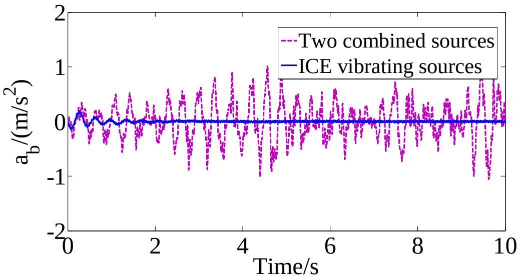
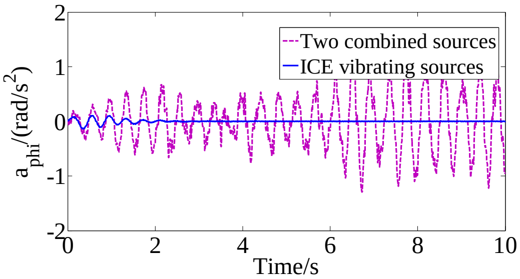
and whenICE engine operates at the speed of 1680prm (vehicle speed of 0 km/h)

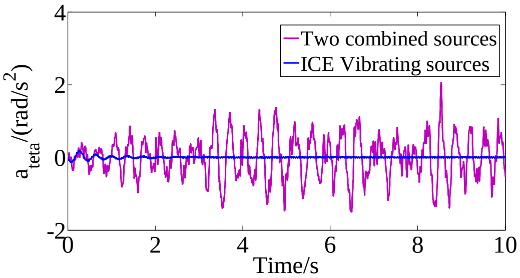
The simulation results of the time domain acceleration responses of the vertical motion (a_b), pitch and roll angles (a_{phi} and a_{teta}) of vehicle body are shown in Figure 4when the vehicle moves on ISO class Dsurfaces road condition and ICE engine operates at the speed of 1400prm (vehicle speed of 48 km/h)and whenICE engine operates at the speed of 1400prm (vehicle speed of 0 km/h). Similarly,the obtained results of Figure 4 show that the peak amplitude values of the time domain acceleration responses of the vertical motion (a_b), pitch and roll angles (a_{phi} and a_{teta}) of vehicle body with ICE vibrating sources respectively increase in comparison without ICE vibrating sources.Therefore, it must be taken care of for optimal design of ICE mounting sytem.



(a) Vertical motion of vehicle body



(b) Pitch angle of vehicle body



(c) Roll angle of vehicle body

Figure 4. The simulation results of the time domain acceleration responses of the vertical motion (a_b), pitch and roll angles (a_{phi} and a_{teta}) of vehicle bodywhen the vehicle moves on ISO class D surfaces road condition and ICE engine operates at the speed of 1400prm (vehicle speed of 48 km/h)and whenICE engine operates at the speed of 1400prm (vehicle speed of 0 km/h).

IV.CONCLUSION

In this study, a full-vehicle dynamic modelunder the combination of two excitation sources such as internal combustion engine and road surface excitationsis established to evaluate their effect on vehicle ride comfort.The time domain acceleration responses of the vertical motion, pitch and roll angles of vehicle body are chosen as objective functions to evaluate the influence of vibrating excitation sources on vehicle ride comfort.The obtained results show thatthe peak amplitude values of a_b, $a_{phi}$and a_{teta} with ICE vibrating sources respectively increase in comparison without ICE vibrating sourceswhich indicates that ICE vibrating sources have a significant effect on vehicle ride comfort and VES must be taken care of for optimal design of ICE mounting sytem.

REFERENCES

[1]. Quynh, L.V. et al., 2019. Influence of damping coefficient into engine rubber mounting system on vehicle ride comfort. Vibroengineering PROCEDIA, 29, pp.112–117. Available at: http://dx.doi.org/10.21595/vp.2019.21084.

[2]. Guo Rong, Gao Jun, Wei Xiaokang, Influence of hydraulic engine mounts on engine shake based on full vehicle model. Vibroengineering PROCEDIA, Vol. 10, 2016, p. 376-381.

[3]. Ta Tuan Hung, Le Van Quynh, Dang Viet Ha, Canh Chi Huan, Bui Van Cuong and Hoang Anh Tan, 2021. A comparison of vehicle ride comfort performance of hydraulic engine mount system with rubber engine mount system, ARPN Journal of Engineering and Applied Sciences,Vol. 16 No. 23, Page No : 2611-2619

[4]. Nguyen Tien Han, Do Van Quan, Doan Thanh Binh, Nguyen Thanh Cong. Effects of Internal Combustion Engine Vibrations on Vehicle Ride Comfort, World Journal of Research and Review (WJRR) ISSN: 2455-3956, Volume-12, Issue-6, June 2021 Pages 25-28.

[5]. Tuan, N.K., Van Hai, V., Thai, H.A. (2019). Influence of Engine Torque on Vehicle Ride Comfort. In: Fujita, H., Nguyen, D., Vu, N., Banh, T., Puta, H. (eds) Advances in Engineering Research and Application. ICERA 2018. Lecture Notes in Networks and

Systems, vol 63. Springer, Cham. https://doi.org/10.1007/978-3-030-04792-4_48

[6]. R. Li, W. Chen, C. Liao, Hierarchical fuzzy control for engine isolation via magnetorheological fluid mounts, Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering. 224(2): 175-187.

[7]. ISO 8068, Mechanical Vibration-Road Surface Profiles-Reporting of Measured Data. International Organization for Standardization, 1995.

[8]. Dinh Cong Hao, Study control for semi-active engine mounting system via vehicle ride comfort. Master thesis of Thai Nguyen University of Technology, 2019.

[9]. Vu Anh Duong, Design optimization for engine mounting system via vehicle ride comfort. Master thesis of Thai Nguyen University of Technology, 2021