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Performance Analysis of Cab' Hydraulic Isolation System on a Double-Drum Vibratory Roller Ride Comfort

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ABSTRACT: In order to analyzethe ride comfort performance of cab' hydraulic isolation systemof a double-drum vibratory roller, a half- vehicle dynamic model is established under the different operating conditions. Then, two mathematical modelswith the damping characteristics of the hydraulic and original rubberisolations of are set up to analyze and compare the ride comfort performance of theirs. The weighted root mean square (rms) of acceleration responses of the vertical driver's seat and pitch vibration of cab (a_{ws} and a_{wphi}) according to the ISO 2631:1997(E) standard is chosen as objective functions.The study results indicate that the a_{ws} and a_{wphi} values with cab's hydraulic isolation system reduce significantly in comparison with those of the original rubber cab isolation system, which means that the performance of drum's isolation systems is better than the original vehicle in improving the vehicle ride comfort.

KEYWORDS: Vibratory roller, hydraulic isolation system, rubber isolation system, cab, ride comfort

I. INTRODUCTION

In recent years, vibration roller market has required increasingly not only on working capacity but also ride comfort. Thus, in order to reduce the effect of vibration to operators, identification and elimination of vibration sources are the most important tasks to achieve optimum design. In realistic working conditions, a vibratory roller operates and moves on various kinds of soil ground, the vibration excitation sources causing vehicle's body vibration are only the excitations of the interaction between wheel and deformation ground soil, but also are the excitations of vibration drum and engine which is one of the main reasons for driver's health as well as labor efficiency. The characteristics of traditional rubber isolation system of vibratory roller of cab werereviewed and investigatedits effect on vehicle ride comfort using CAD/CAE model and vehicle dynamic models. The characteristics of the hydraulic cab isolation system of an earth-moving machinery cab were analyzed and evaluated by a 3D cab dynamic model with six degrees of freedom [2]. In order to improve the ridecomfort of the vibratory roller of cab, the design parameters of cab's auxiliary rubber isolation system were optimized using CAD/CAE models [3]. A similar study, the design parameters of cab's main rubber isolation system were optimized using CAD/CAE models [4]. The design parameters of cab's rubber isolation system of single drum vibratory rollerwere optimized by using ahalf-vehicle ride dynamic model anda method of combining a genetic algorithm (GA) and a multi-objective optimization algorithm [5]. The design parameters of cab's isolation system of a single drum vibratory roller were optimized by using 3D nonlinear dynamic model and the improved genetic algorithm NSGA-II [6]. The hydro pneumatic isolation (HPI) of the cab combined by the high static stiffness and nonlinear viscous damping of the pneumatic isolation; and nonlinear adjustable damping of the hydraulic isolation were proposed to analyzeits effect on the ride comfort of a single drum vibratory roller using a nonlinear dynamic model of the soil compactor interacting with the deformable terrains [7]. The liquid-filled cab mount system (LCMs) with an annular orifice and an original rubber cab mount system (RCMs) was recommended and compared the ride performance

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of a double-drum vibratory roller under the operating conditions [8].

The purpose of this paper is to establish a half-vehicle dynamic model of a double-drum vibratory roller under the different operating conditionsfor analyzing the ride comfortperformance of cab' hydraulic damping rubber isolation system.The weighted root mean square (r.m.s) of acceleration responses of the vertical driver's seat and pitch vibration of cab (a_{ws} and a_{wphi}) according to the ISO 2631:1997(E) standard is chosen as objective functions. The ride comfort performance of cab' hydraulic damping rubber isolation system isanalyzed and compared with cab's original rubber isolation system under the different operating conditions.

II. HALF-VEHICLE DYNAMIC MODEL

A half-vehicledynamic model of a double-drum vibratory rollerconsists of the masses of the dynamic drums, frame, cab and driver's seat, m_{di}, m_b, m_c and m_s, asshown in Figure 1. where, $I_b$and I_c are the inertia moment of the vehicle dody and cab body,respectively; k_{si}, $k_{di}$and k_s are the stiffness coefficients of elastic road surfaces, front and rear mount systems of dynamic drums and suspension system of driver seat, respectively; c_{si}, c_{di}, c_s are the damping coefficients of elastic road surfaces, front and rear mount systems of dynamic drums and suspension system of driver seat, respectively; z_{di}, z_b, $z_c$and z_s are the the front dynamic drum, rear dynamic drum, vehicle body, cab body and driver seat displacements, respectively; φ_b and φ_c are the pitch angular displacements of vehicle body and cab body, respectively; q_i are the excitations of ground surface roughness at front and rear dynamic drums, respectively; $l_j$are the distances; $F_{ei}=F_{0i}\sin(\omega_i t)$ are the excitation forces for the dynamic drums; F_{0i} are the force amplitudes; ω_i are the angular frequencies of the vibrators; F_{ci} are the vertical forces of cab's isolation system and v is the vehicle speed (i=1÷2, j=1÷6).

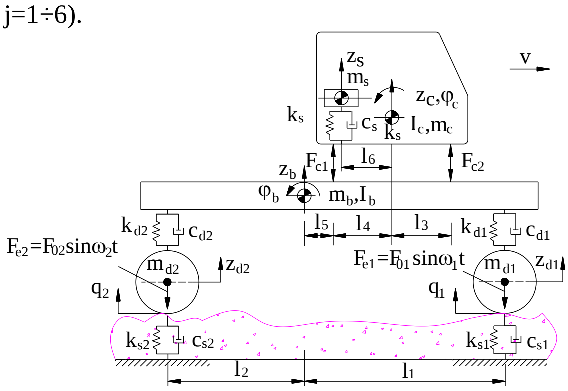

Figure 1. Half-vehicle dynamic model ofa double-drum vibratory roller

The equations of motion of the bodies in Fig.2 could be written by using a combined method of the multi-body system theory and D'Alembert's principle as follows.

The equations of motion for the vertical and pitch motions of cab are written as follows

$$m_c\ddot{z}_c = F_s - F_{c1} - F_{c2} \quad (1)$$

$$I_c\varphi_c = F_s l_6 - F_{c1}l_3 + F_{c2}l_4 \quad (2)$$

The equations of motion for the vertical and pitch motions of vehicle are written as follows

$$m_b\ddot{z}_b = F_{c1} + F_{c2} - F_{d1} - F_{d2} \quad (3)$$

$$I_b\varphi_b = -F_{d1}l_1 + F_{d2}l_2 + \quad (4)$$
$$+F_{c2}l_5 + F_{c1}(l_3 + l_4 + l_5)$$

The equation of driver seat motion is written as follows

$$m_s\ddot{z}_s = -F_s \quad (5)$$

where, F_s is the vertical driver seat force which is determined by Eq. (6), F_{ci} are the vertical forces of cab isolation system and F_{di} are the vertical forces of front and rear mount systems of drums which could be determined through two cases.

$$F_s = [k_s(z_s - z_c + l_6\,\varphi_c) + c_s(\dot{z}_s - \dot{z}_c + l_6\,\dot{\varphi}_c] \quad (6)$$

Case 1: Vehicle moves into the construction site

Vehicle moves on the ground surface and dynamic drums is uncompressed.The drum of vibratory roller contact with the rigid ground surface. The vertical forces of front and rear mount systems of drums are defined as

$$F_{d1} = k_{d1}\left(z_f + l_1\varphi_f - q_d\right) + c_d\left(\dot{z}_f + l_1\dot{\varphi}_f - \quad (7)\right.$$

$$F_{d2} = k_{d2}\left(z_f - l_2\varphi_f - q_d\right) + c_{d2}\left(\dot{z}_f - l_2\dot{\varphi}_f \quad (8)\right.$$

where, q_i are the excitations of the rigid ground surface which is described based on the International Standards Organization (ISO 8608) [10].

Case 2: Vehicle operates in the construction site

Condition1:When both front and rear dynamic drums compact on the original place,the motion equations of the front and rear dynamic drums are written as follows

$$m_{d1}\ddot{z}_{d1} = F_{e1} + F_{d1} - k_{s1}z_{d1} - c_{s1}\dot{z}_{d1} \quad (9)$$

$$m_{d2}\ddot{z}_{d2} = F_{e2} + F_{d2} - k_{s2}z_{d2} - c_{s2}\dot{z}_{d2} \quad (10)$$

Condition 2:When both front dynamic drum compact on the elastic soil grounds,and rear dynamic drum moves on the rigid ground surfaces, the equation of motion for front dynamic drum is determined by Eq.(9) and the vertical forces of rear mount systems of dynamic drum is determined by Eq.(8).

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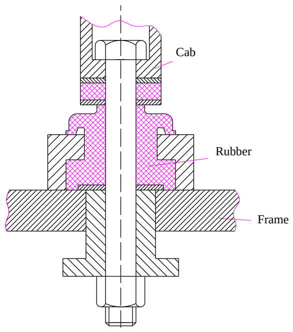
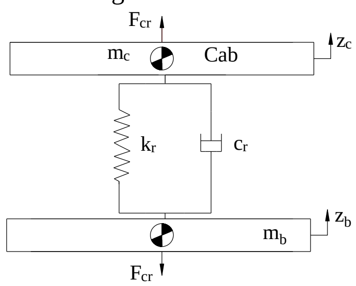
A structural diagram of rubber cab isolation (RCI) is shown in Figure 2 (a) and adynamic model ofRCI is shown in Figure 2 (b) which consists of the masses of fame and cab, m_f, and m_c, the elastic stiffness of rubber parts and damping coefficient due to the internal frictions, k_r, and c_r. A structural diagram of hydraulic cab isolation (HCI)shown in Figure 3 (a) and anonlinear dynamical modelof HCM is shown in Figure 3(b) which consists ofthe pressure in chamber 1 and chamber 2, p_1 and p_2.

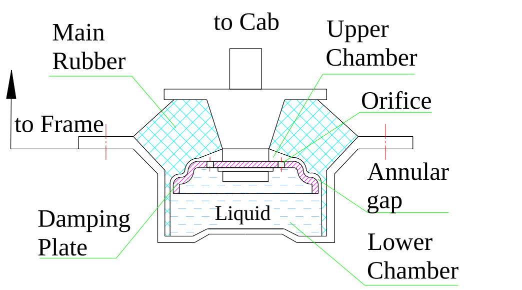


(a) Structural diagram of a rubber cab isolation

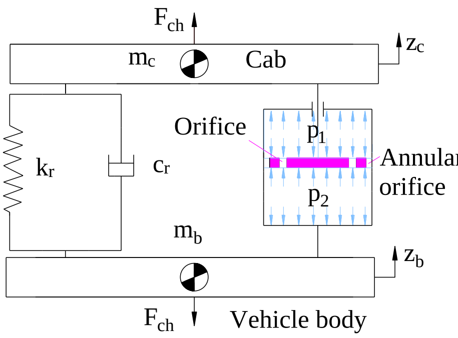


(b) Dynamic model of a rubber cab isolation

Figure 2. Model of rubber isolation



(a) Structural diagram of a hydraulic cab isolation



(b) Nonlinear dynamical model of a hydrauliccab isolation

Figure 3. Model of hydraulic isolation

Based on Fig. 2 (b), the total vertical forces of RCI could be achieved by

$$F_{cr} = k_r\left(z_c - z_b\right) + c_r\left(\dot{z}_c - \dot{z}_b\right) \quad (11)$$

Based on Fig. 3 (b), the total vertical forces of RCI could be achieved by

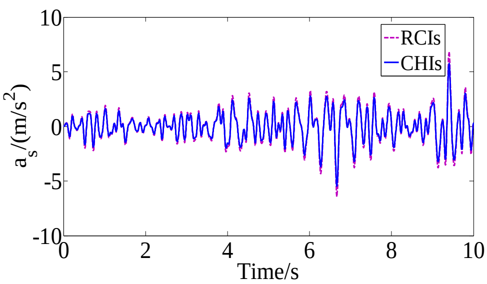
$$F_{cr} = k_r\left(z_c - z_b\right) + c_r\left(\dot{z}_c - \dot{z}_b\right) + \quad (12)$$
$$+ c_f\left|\dot{z}_c - \dot{z}_b\right|\left(\dot{z}_c - \dot{z}_b\right)$$

where, c_f is the damping coefficient through the orifices and the annular gap.

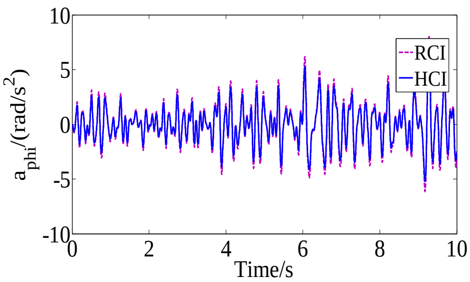
III. RESULTS AND DISCUSSION

In order to analyze and evaluatethe ride comfort performance of HCI of vibratory roller compared with RCI under the different operating conditions, the differential equations of motion of vehicle are simulated using the MATLAB/Simulink software with design parameters of vehicle, RCI, HCI in the references [1-2].

Case 1: The comparison results of the time domain of the vertical driver's seat and pitch vibration of cabwith RCIs and HCIs when the vehicle moves on very poor ground surface condition (ISO class E) at v=5 km/hare shown and Figure 4.



(a)The comparison of the time domain of the vertical driver's seat with HCIs and RCIs



(b)The comparison of the time domain of the pitch vibration of cabwith HCIs and RCIs

Figure 4. The comparison of time domain of the vertical driver's seat and pitch vibration of cabwith HCIs and RCIs when the vehicle moves on very

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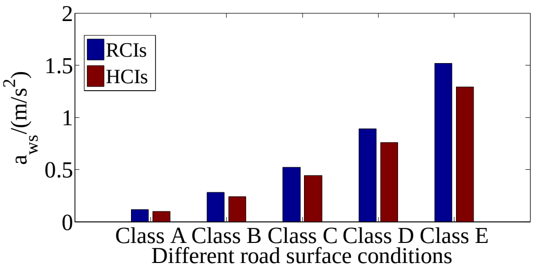
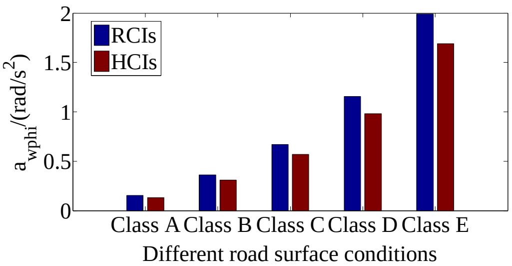
poor ground surface condition (ISO class E) at v=5 km/h

The obtained results of Figure 4 show that the peak amplitude values of the time domain of the vertical driver's seat and pitch vibration of cabwith HCIs respectively reduce in comparison with RCIs.

In order to compare performance of HCIs and RCIs, the vehicle moving on five road surface conditions (from ISO class A to ISO class E in ISO 8068 [9]) at vehicle speed of 5 km/h. The values of the weighted r.m.s. acceleration of the vertical driver's seat (a_{ws}) and the pitch vibration of cab(a_{wphi}) are shown in Fig 5. Fig 5 shows that the values of a_{ws} and $a_{wphi}$with HCIs respectively reduce in comparison with RCIs underthe different road surface conditions and the values of a_{ws} and $a_{wphi}$with HCIs increase fast when vehicle moves on the worse road surface conditions, especially on ISO class C, ISO class D and ISO class Eand that leads to a decrease in vehicle ride comfort.



(a) The vertical driver's seat

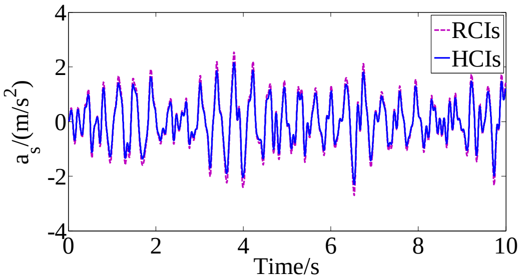


(b) The pitch vibration of cab

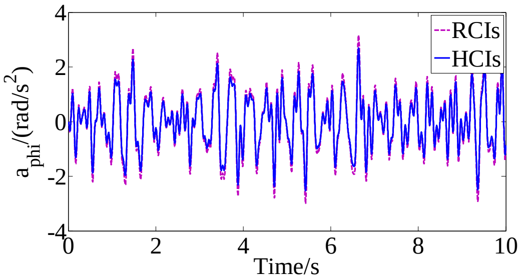
Figure 5. The comparison ofthe a_{ws} and a_{wphi} values with HCIs and RCIswhen the vehicle moves under the different road surface conditions at vehicle speed of 5 km/h.

Case 2: The comparison results of the time domain of a_s and a_{cphi} with HCIs and RCIswhen the front drum compacts with the elastic soil ground parameters as k_{s1}=1.0x10^7 N/m, c_{s1}=2.1x10^5 (Ns/m) and the front dynamic excitation force as F_{01}=0.128 x10^6 N, f_1=48 Hz and rear dynamic drum moves on very poor ground surface condition (ISO class E) at v= 2 km/h are shown in Fig.6.

The obtained results of Figure 6 show that the peak amplitude values of the time domain of the vertical driver's seat and pitch vibration of cabwith HCIs respectively reduce in comparison with RCIs.The ride performance of HCIsis better than RCIs, becausethe structure of HCIs is designed accordingthe orifices and the annular gap whichincrease the coefficient of hydraulic damping. The damping coefficient of isolation greatly affects the ride comfort of vehicle.



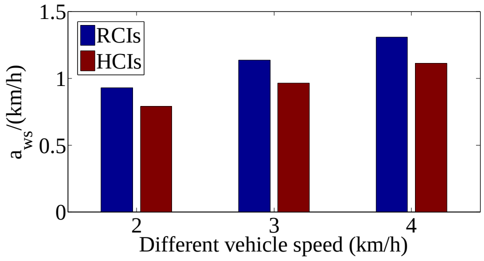
(a)The comparison of the time domain of the vertical driver's seat with HCIs and RCIs



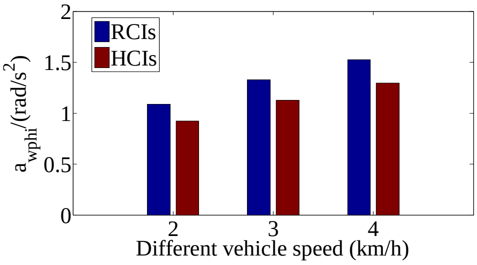
(b)The comparison of the time domain of the pitch vibration of cabwith HCIs and RCIs

Figure 6. The comparison of time domain of the vertical driver's seat and pitch vibration of cabwith HCIs and RCIs when the front drum compacts with the elastic soil ground parameters as k_{s1}=1.0x10^7 N/m, c_{s1}=2.1x10^5 (Ns/m) and the front dynamic excitation force as F_{01}=0.128 x10^6 N, f_1=48 Hz and rear dynamic drum moves on very poor ground surface condition (ISO class E) at v= 2 km/h

Similar to Case 1, in order to compare performance of HCIs and RCIs, the front drum compacts with the elastic soil ground parameters as k_{s1}=1.0x10^7 N/m, c_{s1}=2.1x10^5 (Ns/m) and the front dynamic excitation force as F_{01}=0.128 x10^6 N, f_1=48 Hz and rear dynamic drum moves on very poor ground surface condition (ISO class E) at from vehicle speed of 2 km/h to vehicle speed of 5 km/h.The values of the weighted r.m.s. acceleration of the vertical driver's seat (a_{ws}) and the pitch vibration of cab (a_{wphi}) at the different vehicle speedare shown in Fig 7. Fig 7 shows that the values of a_{ws} and $a_{wphi}$with HCIs respectively reduce in comparison with RCIs underthe different vehicle speed conditions.The values of a_{ws} with HCIs reduce by 12.53%, 15.31% and 17.65% in comparison with RCIsand the values of a_{wphi} with HCIs reduce by 11.94%, 14.57% and 16.77% in comparison with RCIswhen the vehicle compression speed respectivelyincrease.The values of a_{ws} and $a_{wphi}$with HCIs increase fast when the vehicle compression speed respectivelyincrease and that leads to a decrease in vehicle ride comfort.



(a) The vertical driver's seat



(b) The pitch vibration of cab

Figure 7. The comparison ofthe a_{ws} and a_{wphi} values with HCIs and RCIswhen the front drum compacts with the elastic soil ground parameters as k_{s1}=1.0x10^7 N/m, c_{s1}=2.1x10^5 (Ns/m) and the front dynamic excitation force as F_{01}=0.128 x10^6 N, f_1=48 Hz and rear dynamic drum moves on very poor ground surface condition (ISO class E) at from vehicle speed of 2 km/h to vehicle speed of 5 km/h

IV. CONCLUSION

In this study, a half- vehicle dynamic model ofa double-drum vibratory roller proposed to analyzethe ride comfort performance of HCIs compared with that of RCIsunder the different operating conditions. Some conclusions can be drawn from the results of the analysis:(1) The peak amplitude values of the time domain of the vertical driver's seat and pitch vibration of cabwith HCIs respectively reduce in comparison with RCIs and the values of a_{ws} and $a_{wphi}$with HCIs respectively reduce in comparison with RCIs underthe different road surface conditions at case 1; (2) The values of a_{ws} with HCIs reduce by 12.53%, 15.31% and 17.65% in comparison with RCIsand the values of a_{wphi} with HCIs reduce by 11.94%, 14.57% and 16.77% in comparison with RCIs when the vehicle compression speed respectivelyincrease at case 2.

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