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Overview of Cab's Isolation system in Direction of Improving Construction Machinery Ride Comfort

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***Abstract*— Construction machinery ride comfort plays an important role in protecting the health and productivity of the drivers. The goal of this paper is to provide an overview of research on ride comfort characteristics of cab's isolation systems of construction machines. From traditional isolation systems to modern systems, their ride comfort effects are analyzed based on the literatures. Types of isolation system applied to construction machinery cab include traditional rubber isolation system (TRIs), Hydraulic isolation system (HIs), Hydro pneumatic isolation system (HPIs), Semi-active hydrauric isolation system (SHIs) and Semi-active hydraulic-pneumatic isolation system (SHPIs) are discussed in this paper. The study results have shown the advantages and disadvantages of cab's isolation systems being applied on construction machines. In addition, the study results could provide ideas for researchers in the field of construction machinery ride comfort.**

***Index Terms*— construction machinery, cab, isolation system, ride comfort.**

I. Introduction

Currently, the construction machinery market not only competes fiercely in terms of machine efficiency, but also competes in terms of machine ride comfort and noise. Most construction machines are not equipped with an elastic suspension system between the axle and the chassis. Vibration sources are transmitted to the operator's body through cab's isolation system and drive's suspension system. The low-frequency vibration characteristics of the vibratory roller with the traditional rubber mounts, the hydraulic mounts, and the pneumatic mounts were proposed and analyzed for their influence on on-off vibratory roller ride comfort [1]. The ride comfort characteristics of cab's metal rubber isolation system of a single drum vibratory roller under the different soil grounds were analyzed and evaluated using a 3-DOF vibration mode with Adam D. and Kopf F's elastic-plastic soil model, Bekker's hypothesis of the soft soil ground [2]. The ride comfort characteristics of cab's metal rubber isolation system of vibratory roller via finite element model were optimized to improve system efficiency according to the two points response amplitude in the direction of forward motion on the cab to reach the minimum value in the low frequency range [3]. Similarly, the ride comfort characteristics of cab's metal rubber isolation system of vibratory roller via 3D nonlinear dynamic model were optimized to improve system efficiency based on the improved genetic algorithm NSGA-II [4], as shown in Fig.1.

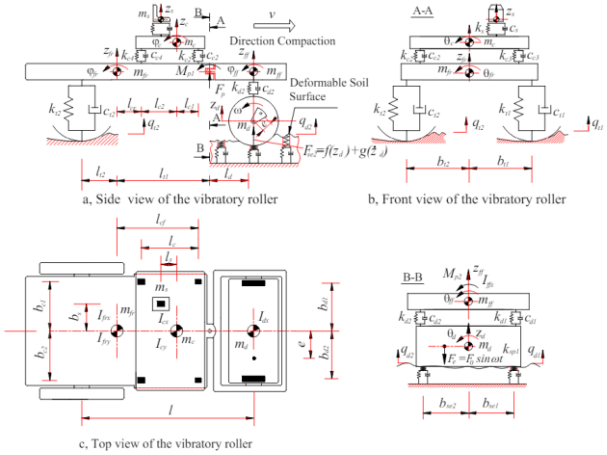

Figure 1. 3-D nonlinear dynamic model of vibratory roller [4]

A comparison of ride comfort characteristics of two cab's isolation systems such as rubber cab mount system (RCIs) and liquid-filled cab isolation system (LCIs) was proposed and analyzed unsing a half-vehicle ride dynamic model of a double-drum vibratory roller under two survey cases [5]. For a similar analysis, a comparison of ride comfort characteristics of two cab's isolation systems such as rubber isolation system (RIS) and hydraulic isolation system (HIS) was proposed and analyzed using a six-degree-of-freedom (d.f.) model of the cab [6], as shown in Fig.2.

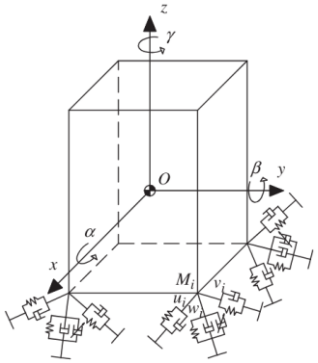

Figure 1. Lumped parameter model of the cab isolation system [6]

The ride comfort characteristics of semi-active cab's hydraulic isolation system of an off-road vibratory roller were recommended and analyzed using an optimal fuzzy-PID control method and an off-road vehicle roller dynamic model [7]. Similarly, the ride comfort characteristics of semi-active cab's hydraulic isolation system were recommended and analyzed using a combined control method of Fuzzy and PID control and a non-linear vehicle dynamic model [8], as shown in Fig.3

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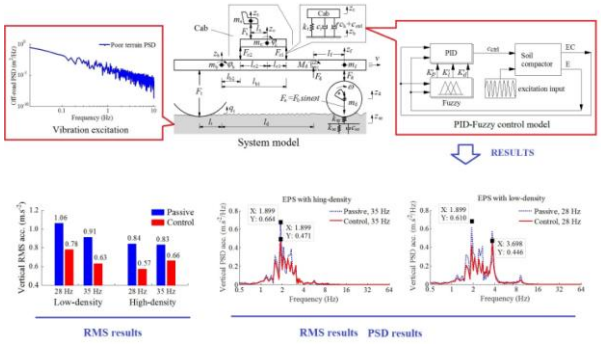


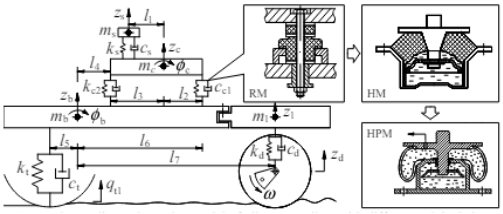
Figure 3. Description of the results of semi-active cab's hydraulic isolation system [8]

The main goal of this paper is to synthesize and analyze several results of research on the ride comfort characteristics of cab isolation systems of construction machines.

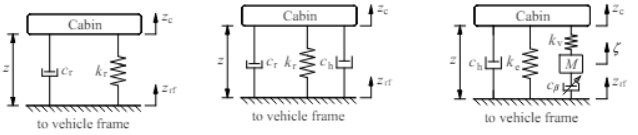
II. ISOLATION SYSTEM OF CAB

A. Rubber isolation (mount) systems of cab

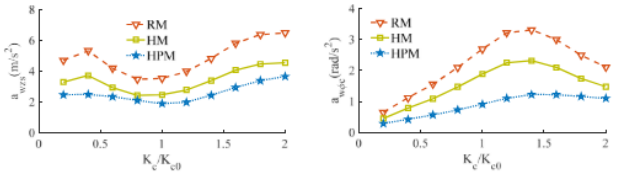
Rubber isolation systems are widely used in the field of vibration and noise reduction. It is commonly used as a vibration isolator for engines and cabs of construction machines. A rubber mount (RM) of cab vibratory roller was compared and analyzed the influence of its design parameters on ride comfort with two types of hydraulic mount (HM) and hydro-pneumatic mount (HPM) [9], as shown in Fig.4



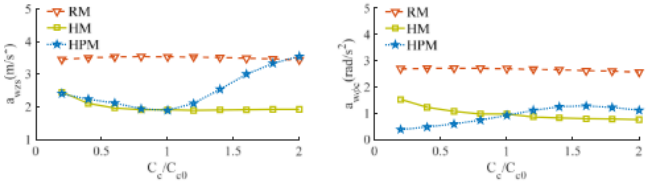
(a) Nonlinear dynamics model of vibratory roller with different cab mounts



(b) RM (c) HM (d) HPM



(e) RMS acceleration responses (a_{wzs}) and ($a_{w\phi c}$) under the different stiffness coefficients



(f) RMS acceleration responses (a_{wzs}) and ($a_{w\phi c}$) under the different damping coefficients

Figure 4. Results of the reference study [9]

From the study results [9], the RMS acceleration responses (a_{wzs}) and ($a_{w\phi c}$) under the different stiffness and damping coefficient of three types of cab's mount systems indicate that the characteristics of non-linear damper and high-static stiffness of the hydro-pneumatic mounts can greatly reduce the vertical driver's seat vibration and cab shaking compared to the traditional rubber mounts and hydraulic mounts. However, many studies have shown the effectiveness of rubber isolation systems in improving the ride comfort of construction machines, especially in the high frequency range [1-5]. A number of studies have been conducted to optimize the design parameters of the cab rubber isolation system to improve ride comfort construction machinery in the low frequency range. Some research results are shown in Table 1.

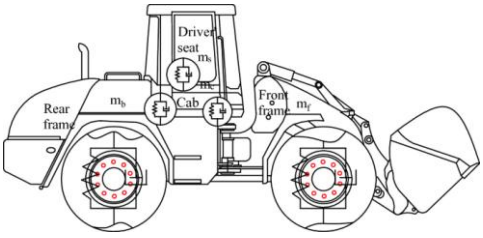
Table 1. Some research results on optimizing design parameters of cab isolation systems for construction machines

Name of the study	Methods and results
Quynh, Le Van, Jian Run Zhang, et al, "Vibration Analysis and Optimal Design for Cab's Isolation System of Vibratory Roller," [3]	The auxiliary isolation system (AIS) for solving the low-frequency sloshing in the direction of forward motion was proposed and its design parameters are optimized according to the two points response amplitude in the direction of forward motion using CAE model. The results showed tha the vibratory roller with AIS could successfully avoids the resonance in frequency band 0~4.63Hz and the amount of cab sloshing is only 0.09×10^{-2} mm much less than 0.78×10^{-2} mm before.
Le, Van Quynh, and Khac Tuan Nguyen. "Optimal Design Parameters of Cab's Isolation System for Vibratory Roller Using a Multi-Objective Genetic Algorithm." [4]	The improved genetic algorithm NSGA-II was proposed to optimize the design parameters of cab's isolation system when vehicle operates under the different conditions. The results indicate that three objective function values were reduced significantly to improve vehicle ride comfort
Van Quynh, L. et al, "Optimal Design of Cab's Isolation System for a Single-Drum Vibratory Roller," [10]	The design parameters of cab's isolation system via genetic algorithm (GA) and a multi-objective optimization algorithm are optimized by the root mean square (rms) values of acceleration responses of the vertical driver's seat (a_{ws}) and cab's pitch angle angle (a_{wcphi}) according to the ISO 2631:1997(E) standard. he study results indicate that the a_{ws} and a_{wcphi} values reduce by 31.88% and 31.27%, respectively in comparison with the original parameters of cab's isolation systems when the vehicle moves on the ISO class D road surface at the vehicle speed v = 5 km/h

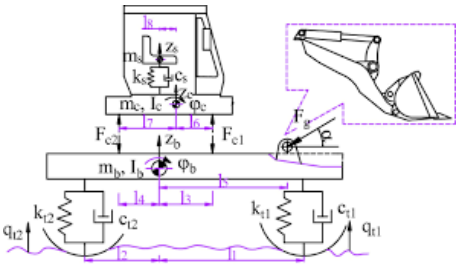
B. Hydraulic isolation (mount) systems of cab

Through analyzing the study results in the above section, the rubber isolation system often achieves a value of small friction coefficient, leading to the suppression of limited vibration sources in the low frequency range, so the damping coefficient of the hydraulic fluid was added to increase the damping coefficient value for the traditional rubber isolation systems. A hydraulic isolation system (HIs) of cab wheel loader with the orifice and the annular orifice was proposed and analyzed under different driving conditions using a half-vehicle dynamic model [11], as shown in Fig.5. The study results show that the amplitude values of the PSD acceleration responses of the vertical driver's seat with

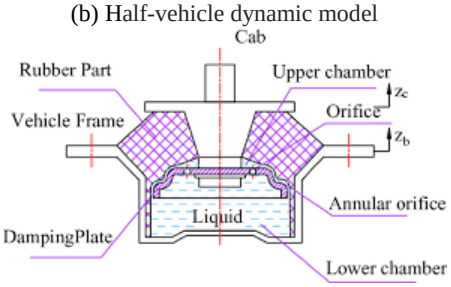
1.5c_0 value of HIs respectively reduce in comparison with 0.5c_0 value of HIs at the low frequency region from 2.0 Hz to 20 Hz.



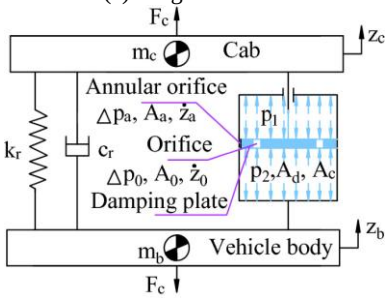
(a) Diagram of cab's isolation system



(b) Half-vehicle dynamic model



(c) Diagram of HIs



(d) Dynamic model of HIs

Figure 5. Results of the reference study [11]

Two mathematical models with the damping characteristics of the hydraulic isolation system and original rubber isolation system were set up to analyze and compare the ride comfort performance of theirs using half- vehicle dynamic model of double-drum vibratory roller. The study results indicate that the a_{ws} and a_{wphi} values with cab's hydraulic isolation system reduced significantly in comparison with those of the original rubber cab isolation system, which means that the performance of cab's isolation systems was better than the original vehicle in improving the vehicle ride comfort [12].

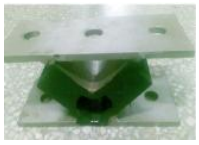
A damper hydraulic mount was studied and combined with the cab's rubber mounts to simulate and evaluate the performance of the ride comfort using a 3-D nonlinear dynamic model of the vehicle interacting with the off-road terrain [13]. he results show that the cab's rubber mounts combined with the damper hydraulic mount are clearly improved the ride comfort under various operating conditions. Especially, with damping coefficient value, c_c=3,4= 1.8 kN.s.m^{-1}, the weighted RMS values of the vertical driver's seat, the cab's pitch and roll angle were greatly reduced by 27.8%, 22.7% and 64.3% in condition of the vehicle traveling, and by 23.8%, 20.0% and 63.7% in condition of the vehicle compacting on an elastic-plastic terrain.

Some study results also show that the peak amplitude values of hydraulic isolation system in the low frequency region more effectively than the traditional rubber isolation system [11], [12], [13]. However, the elastic part still relies on rubber properties, resulting in ride comfort that has not improved significantly [9].

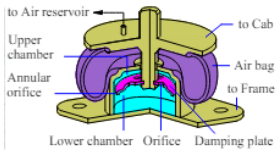
C. Hydro pneumatic isolation (mount) systems of cab

To overcome some limitations of the elastic parts of the two systems of rubber isolation system and rubber-hydraulic isolation system, the hydro pneumatic isolation (mount) systems of cab are researched and applied in construction machines. 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 [9]. The low frequency ride comfort of the hydro pneumatic isolation (HPI) was proposed and analyzed using a 3-D nonlinear dynamic model of the vehicle interacting with the off-road terrain [14], as shown in Fig.6. The study results show that the HPI's characteristics with high static stiffness and nonlinear damping achieved an obvious impact on reducing low frequency vibration and controlling the cab shake of the vehicle in comparison with the traditional rubber isolation system (TRI).

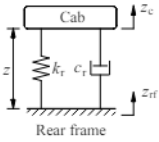
(a) Old rubber isolation



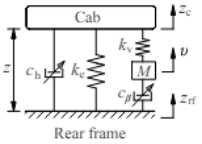
(b) New rubber isolation



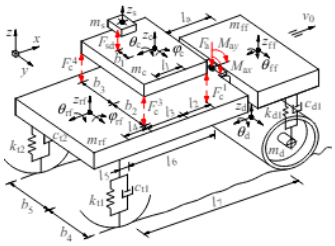
(c) Hydro pneumatic isolation



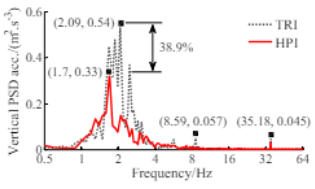
(c) Mathematical model of TRI



(d) Mathematical model of HPI



(e) 3D dynamic model



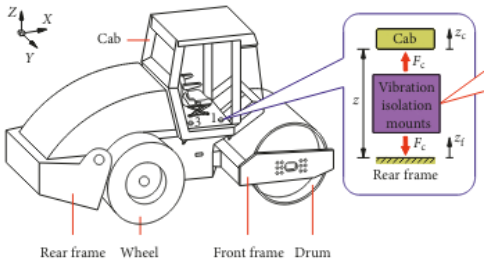
(f)PSD acc. of driver's seat

Figure 6. Results of the reference study [14]

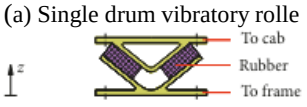
Some study results also show that the peak amplitude values of the hydro pneumatic isolation system (HPIs) of the cab in the low frequency region more effectively than the traditional isolation systems [9]. [11], [12], [13], [14]. However, all of the above isolation systems of cab are passive types and the damping coefficient values could not be changed according to operating conditions.

D. Semi-active isolation (mount) systems of cab

In order to improve the ride comfort of construction machines, cab's hydraulic mount system were analyzed to prevent vibration sources transmitting to the cab. An optimal fuzzy-PID control method for semi-active cab's hydraulic isolation system was proposed based on an off-road vehicle roller dynamic model to analyze the low-frequency performance of semi-active cab's hydraulic mounts under the different operating conditions [7], [8], as shown in Fig.7. The study results show that the semi-active cab's hydraulic mounts with optimization have an obvious effect on mitigating the cab shaking and improving the ride comfort in comparison with passive cab's hydraulic mounts and semi-active cab's hydraulic mounts without optimization.

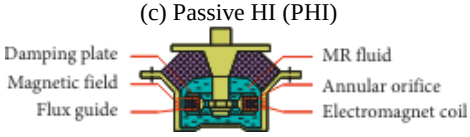


(a) Single drum vibratory rolle

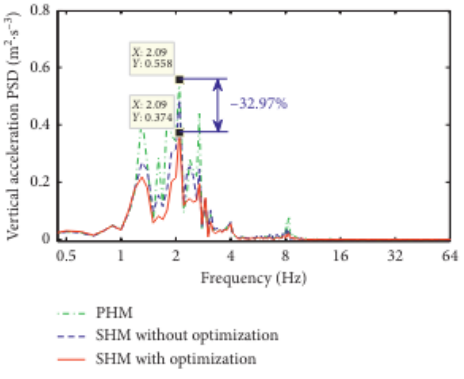


(b) TRI

(c) Passive HI (PHI)



(d) Semi-active HI (SHI)

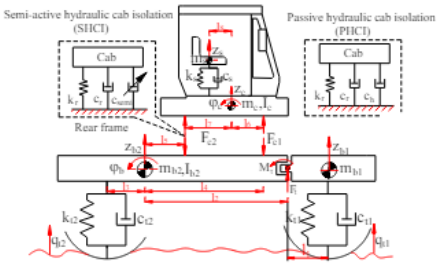


(e) PSD acc. of vertical driver's seat

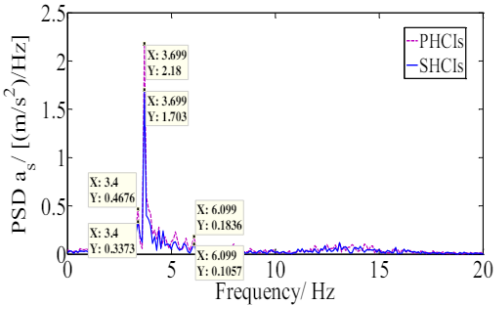
Figure 7. Results of the reference study [7]

In the condition of the vehicle traveling [7], the weighted RMS acceleration responses and the PSD acceleration responses of the vertical driver's seat, cab's pitch, and roll vibrations of SHIs with optimization were lower than both PHIs and SHIs without optimization. Particularly, the weighted RMS values of SHIs with optimization are strongly reduced in comparison with PHIs by 34.99%, 42.56%, and 41.72%, respectively.

A Fuzzy –PID controller was proposed to design for control of the damping coefficient of a semi-active hydraulic isolation system of cab (SHCIs) for an earth-moving machinery using a vehicle - road coupled interaction model [15], as shown in Fig.8. The study results have been shown that the peak amplitude values of a_s and a_{cphi} with SHCIs respectively decrease compared to PHCIs that leads to a significant improvement in ride comfort of wheel loader and the peak amplitude values of PSD a_s and a_{cphi} with SHCIs respectively reduce by 38.63 %, 28.09%, 73.69 % and 47.93 %, 82.34 % compared to PHCIs at low frequency excitations of ground surface.



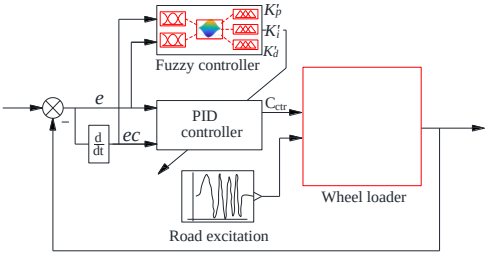
(a) Vehicle - road coupled interaction model



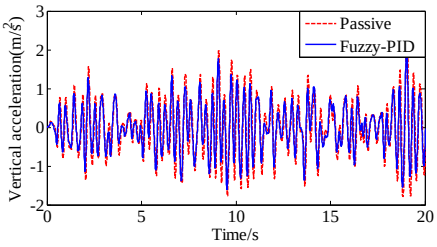
(b) PSD acc. of vertical driver's seat

Figure 8. Results of the reference study [15]

A fuzzy self-tuning of PID controller was designed to control the damping coefficient of semi-active hydrauric isolation system (SHIs) for a wheel loader using a vehicle - road coupled interaction model [16], as shown in Fig.8.



(a) Diagram of Fuzzy –PID controler



(b) Acc. of vertical driver's seat

Figure 8. Results of the reference study [16]

The study results have shown that the values of a_{ws} and a_{wcphi} with SHIs using Fuzzy-PID controller respectively decreased by 19.72 % and 27,97 % compared to PHIs that leads to a significant improvement in ride comfort of wheel loader under survey conditions.

The semi-active hydraulic-pneumatic isolation system (SHPIs) was then developed to further improve the ride quality [17]. The study results indicated that the a combined hydraulic-pneumatic isolation system (CHPIs) had an obvious effect on improving the ride quality and reducing the cab shaking compared to the traditional rubber isolation system (TRIs) under various simulation conditions. Similarly, a semi-active cab's HPIs of a vibratory roller were controlled by using the Fuzzy controller [18], and the study results indicated that the ride comfort of the driver's seat and the shaking of the cab were greatly affected under the deformable soil grounds, especially under a soft soil ground. Semi-active isolation systems of cab will continue to be optimized in the future to improve the ride comfort of construction machines.

III. Conclusion

Some isolation systems of cab construction machinery applied to construction machines include traditional rubber isolation system (TRIs), Hydraulic isolation system (HIs), Hydro pneumatic isolation system (HPIs), Semi-active hydrauric isolation system (SHIs) and Semi-active hydraulic-pneumatic isolation system (SHPIs) were synthesized and analyzed based on the literatures. The major conclusions can be drawn from the analysis results as follows: (i) The ride effectiveness of TRIs reduces peak amplitude at high frequencies; (ii) HPIs has a very good effect in reducing the peak amplitude in the low frequency range, it significantly improves ride comfort compared to TRIs; (iii) SHIs and SHPIs significantly improves ride comfort compared to TRIs and HPIs. SHIs and SHPIs will continue to be optimized in the future to improve the ride comfort of construction machines.

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