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Analysis of the influence of road surface conditions on wheel loader ride comfort

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ABSTRACT: *Ride comfort is one of the important indicators to evaluate the product quality of construction machinery. This paper focuses on analyzing the influence of road surfaceconditions on wheel loader ride comfort. To analyze its effect on vehicle ride comfort,a half -vehicle dynamic model of wheel loaderis established under random road surface excitation.Three poor road surface conditions are selected and analyzed their effects on vehicle ride comfort based on ISO 2631-1(1997).The obtained results clearly show that road surface conditions greatly affect the ride comfort of the vehicle, especially poor road conditions.The study results not only analyze the influence of road surface conditions on vehicle ride comfort, but also provide useful reference for construction machinery managers to improve productivity and operational safety.*

KEYWORDS: *Wheel loader, dynamic model, road surface condition, ride comfort.*

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I. INTRODUCTION

The structure of construction machinery is usually not equipped with a suspension system to elastically connect the axle and the body, so the vibrationsare transmitted to driver's body mainly through the cab's vibration isolation system and driver's seat suspension system. Huan, et al., (2023) [1] proposed a 1/2 dynamic model of wheel loader to evaluate the effectiveness of hydraulic isolation system (HIS) of cab with the orifice and the annular orifice on ride comfort under different driving conditions and the study results showed that the vibration reduction efficiency of HIS was very good under low excitation frequency. Nguyen Dinh Tan et al., (2024) [2] discussed 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 hydraulic isolation system (SHIs) and Semi-active hydraulic-pneumatic isolation system (SHPIs) and the study results showed thatthe advantages and disadvantages of cab's isolation systems were applied on construction machines. Le Van Quynh et al. (2019) [3]proposeda 3D nonlinear dynamic model of a single drum vibratory roller based on the analysis of nonlinear geometric characteristics of wheel-deformation of soil ground contact to analyze theinfluence of design parameters of cab's isolation system on vibratory roller ride comfort under the deformed ground surfaces and the results showed that the range of stiffness and damping coefficient values of the system achieved theminimum objective function values to improve the ride comfort.Sun X, Zhang J., (2012) [4] proposed a6-DOF (Degrees of Freedom) model of earth-moving machinery cab using hydraulic mounts to analyze their hydraulic characteristics to ride comfort of the cab. To improve the ride comfort of construction machinery, Le Van Quynh, et al., (2021) [5] proposed a Fuzzy –PID controller for control of the damping coefficient of a semi-active hydraulic cab isolation system (SHCIs) for an earth-moving machinery and the results showed thatthe SHCIperformance significantly improved the earth-moving machinery ride comfort.Hoang Anh Tan, et al., (2023) [6] proposeda fuzzy self-tuning of PID controller to control the damping coefficient of a semi-active cab isolation system (SCIS) for a wheel loader and the results showed thatthe SCISperformance significantly improved the wheel loader ride comfort. The aim of this study is to propose ahalf-vehicle dynamic model of wheel loaderfor analyzing the influence of road surface conditions on wheel loader ride comfortbased on ISO 2631-1(1997).

II. DYNAMIC MODEL OF WHEEL LOADER

A1/2 dynamic model of wheel loader is developed based on reference [6], as shown in Fig.1, where, m_{b1} is the masses of the bucket, front axle, front frame and other parts above the front wheel, m_{b2} and I_{b2} are the masses and mass inertia momentsof the engine,powertrain, rear axle and other parts above the rear wheel, respectively, m_c and I_c are the mass and mass inertia moment of cab body, k_{ti} are the stiffness coefficient of the tires, c_{ti} are the damping coefficient of the tires, k_s is the stiffness coefficient of driver seat suspension system, c_s is the damping coefficient of driver seat suspension system, F_{ci} are the vertical forces of cab isolation system, l_j are the calculated distances fordetermining the coordinates, F_t and M_t are the replacement force and moment for the front vehicle body mass assembly, respectively, z_{bi}, z_c and z_s are the vertical displacements of the vehicle body, cabin and driver's seat and q_{ti} are road surface excitations (i=1÷2, j=1÷9).

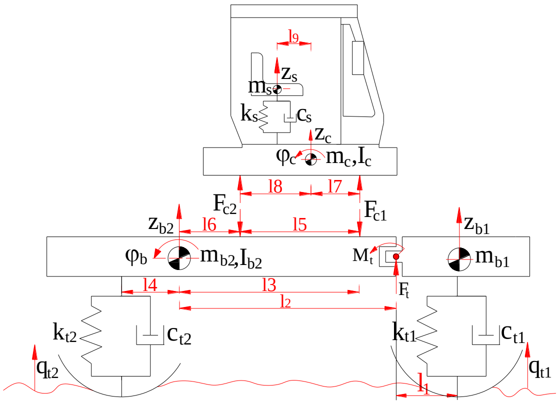


Fig.1.1/2 dynamic model of wheel loader

Currently, there are many methods to establish the differential equations of motion of the mechanical system such as Lagrange equations, D'Alembert principle, Jourdain principle combined with Newton - Euler equation. However, to facilitate computer simulation, this study uses D'Alembert principle combined with the theoretical basis of multi-body systems to establish a system of differential equations describing the vehicle vibration. Based on the multi-body system, separate the objects from the mechanical system and replace them with linked reactions. Then use D'Alembert principle to establish a system of differential equations for each object of the mechanical system and then link them together by the relationship of force and moment. The equations of motion based on the reference [6] are written below.

The motion equations of m_b are written as follows

$$m_{b2}\ddot{z}_{b2} = \sum_{i=1}^{2} F_{ci} - F_{t2} + F_t \tag{1}$$

$$I_{b2}\ddot{\varphi}_{b2} = F_{t2}.l_3 - F_t l_2 + \sum_{i=1}^{i=2} F_{ci} l_{i+3} - M_t \tag{2}$$

The motion equations of m_c are written as follows

$$m_c\ddot{z}_c = F_s - \sum_{i=1}^{2} F_{ci} \tag{3}$$

$$I_c\ddot{\varphi}_c = \sum_{i=1}^{i=2} (-1)^{i+1} F_{ci} l_{i+5} - F_s l_8 \tag{4}$$

The motion equation of $m_s$is written as follows

$$m_s\ddot{z}_s = -F_s \tag{5}$$

The road surface excitations: wheel loader often moves on bad ground surface conditions (off-road conditions) such as large amplitude and low frequency of road surfaces. The bad road surface conditions according to ISO 8608: 2016 [7] is selected as excitation functions for vehicle - road coupled interaction model of a wheel loader which is defined as

$$q(t) = \sum_{i=1}^{N} \sqrt{2G_d(n_i)\Delta n_i} \cos(2\pi i \Delta n t + \beta_i) \tag{6}$$

where, $G_d(n_i)$ is the power spectral density (PSD) at frequency n_i which defined from ISO class A to ISO class H according to ISO 8608: 2016, Δn_i is the variance of the road surface profile which depends on the spatial frequency and the time step, β_i is the phase of the harmonic function (rad) which is randomly generated between 0 and π.

III. VEHICLE RIDE COMFORT EVALUATION CRITERIA [9-11]

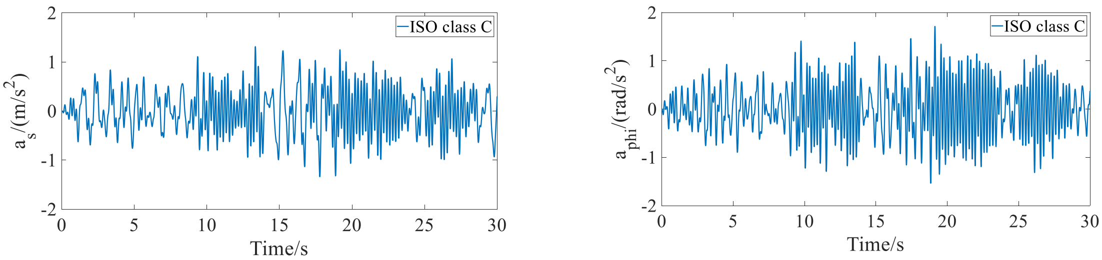
The time-domain method can be applied to evaluate the vehicle ride comfort according to ISO 2631-1 (1997) [8], in this study, the vibration evaluation based on the basic evaluation methods including measurements of the weighted root-mean-square (r.m.s.) acceleration defined as

$$a_{wz} = \left[\frac{1}{T} \int_0^T a_z^{\,2}(t)dt \right]^{1/2} \tag{7}$$

where, $a_z(t)$ is the weighted acceleration (translational and rotational) as a function of time, m/s^2; T is the duration of the measurement, s.

IV. RESULTS AND DISCUSSION

The equations of motion of the vehicle dynamics system in Fig.1are implemented in software MATLAB/Simulink with vehicle parameters of the reference [12]. Poor road surface conditions including ISO class C, ISO class B and ISO class D are selected to analyze their effects on vehicle ride comfort. Driver's seat and pitching angle of cab acceleration responses (a_s and a_{phi}) when vehicle on ISO class D surface condition at v=5km/h and full load are shown in Fig.2.

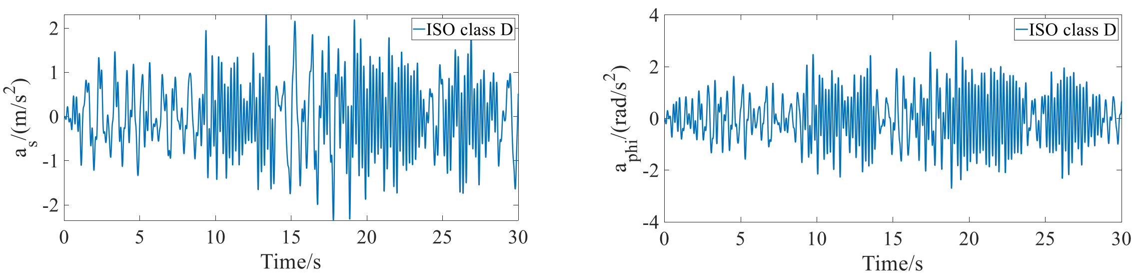


(a) Vertical driver seat (b) Pitching angle of cab

Fig.2. Driver's seat and pitching angle of cab acceleration responses under ISO class C condition

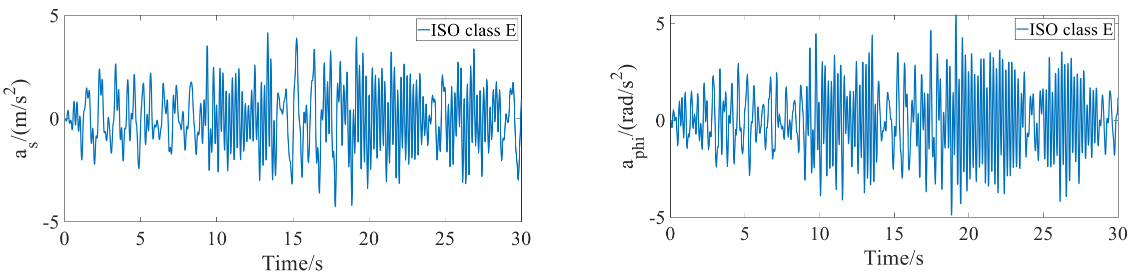
Driver's seat and pitching angle of cab acceleration responses (a_s and a_{phi}) when vehicle on ISO class D surface condition at v=5km/h and full load are shown in Fig.3.

Driver's seat and pitching angle of cab acceleration responses (a_s and a_{phi}) when vehicle on ISO class E surface condition at v=5km/h and full load are shown in Fig.4.



(a) Vertical driver seat (b) Pitching angle of cab

Fig.4. Driver's seat and pitching angle of cab acceleration responses under ISO class D condition



(a) Vertical driver seat (b) Pitching angle of cab

Fig.4. Driver's seat and pitching angle of cab acceleration responses under ISO class E condition

From the results in Fig.2, Fig.3 and Fig.4, the values of the root mean square (r.m.s) acceleration responses of driver's seat and pitch angles of cab (a_{ws} and a_{wphi}) are determined by Eq.(14) according to ISO 2631-1. a_{ws} and a_{wphi}) values are shown in Table 2. The results in Table 2 indicate that a_{ws} and a_{wphi} values increase as the road surface condition become worse which means that the ride comfort of vehicle decreases in the negative direction. The results in indicate that the a_{ws} and a_{wphi} values under ISO class C road surface condition reduce by 35.75%, 48.32% respectively under ISO class D road surface condition.

Table 2.a_{ws} and a_{wphi} values

	a_{ws} (m/s^2)	a_{wphi} (rad/s^2)
ISO class C	0.4416	0.5168
ISO class D	0.8669	1.2442
ISO class E	1.4023	1.6409

V. CONCLUSIONS

In this study, a half-vehicle dynamic model of wheel loaderwas proposed to analyze the influence of road surface conditions on wheel loader ride comfort based on ISO 2631-1(1997). Poor road surface conditions including ISO class C, ISO class B and ISO class D are selected to analyze their effects on vehicle ride comfort. Some conclusions drawn from the obtained results: (i)The a_{ws} and a_{wphi} values increase as the road surface condition become worsewhich means that the ride comfort of vehicle decreases in the negative direction and (ii) The a_{ws} and a_{wphi} values under ISO class C road surface condition reduce by 35.75%, 48.32% respectively under ISO class D road surface condition.The next research direction focuses on analyzing the influence of design parameters of cab's isolation system on wheel roader ride comfort.

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REFERENCES

[1]. Huan, C.C., Ha, D.V., Vu, L.A., Thoan, T.V., Quynh, L.V. (2023). Ride Comfort Evaluation for a Wheel Loader with Cab's Hydraulic Isolation System. Lecture Notes in Networks and Systems, vol 602. Springer, Cham. https://doi.org/10.1007/978-3-031-22200-9_89.

[2]. Nguyen Dinh Tan, Canh Chi Huan, Ngo Thanh Trung, (2024). Overview of Cab's Isolation system in Direction of Improving Construction Machinery Ride Comfort. World Journal of Research and Review (WJRR), Vol.18 (5), pp.04-09.

[3]. Le Van Quynh, Vi Thi Phuong Thao, Nguyen Thanh Cong, (2019). Influence of Design Parameters of Cab's Isolation System on Vibratory Roller Ride Comfort under the Deformed Ground Surfaces. International Research Journal of Engineering and Technology (IRJET), Vol.6 (6), pp.1974-1978.

[4]. Sun X, Zhang J., (2012). Performance of earth-moving machinery cab with hydraulic mounts in low frequency. Journal of Vibration and Control, 20(5):724-735. doi:10.1177/1077546312464260.

[5]. Le Van Quynh, Dang Viet Ha, Bui Van Cuong, Le Anh Vu and Tran Van Thoan, (2021). Improvement of Ride Comfort Quality for an Earth-Moving machinery with Semi-Active Cab Isolation System. E3S Web of Conferences 304, 02012 (2021). https://doi.org/10.1051/e3sconf/202130402012.

[6]. Hoang Anh Tan, Bui Van Cuong, Nguyen Dinh Tan, Nguyen Minh Chau, and Canh Chi Huan, "Improvement of ride quality for a wheel loader with semi-active cab isolation system via fuzzy selftuning of PID controller", JMST, no. FEE, pp. 197–203, Dec. 2023.**DOI:** https://doi.org/10.54939/1859-1043.j.mst.FEE.2023.197-203.

[7]. ISO 8068, (2016). Mechanical Vibration-Road Surface Profiles – Reporting of Measured Data.

[8]. ISO 2631-1, (1997). Mechanical Vibration and Shock-Evaluation of Human Exposure to Whole-Body Vibration, Part I: General Requirements. The International Organization for Standardization.

[9]. Le Van Quynh, Vi Thi Phuong Thao, (2020). Effect of Operating Conditions on Vehicle Ride Comfort and Road Surface Friendliness with Air Suspension System. International Research Journal of Engineering and Technology (IRJET), Vol.7(6), pp. 7671-7675.

[10]. Le Xuan Long, Le Van Quynh, Bui Van Cuong (2018). Study on the influence of bus suspension parameters on ride comfort. Vibroengineering PROCEDIA, Vol. 21, p. 77-82.

[11]. Le Van Quynh, Thao V. T. P., et al (2019). Influence of design parameters of cab's isolation system on vibratory roller ride comfort under the deformed ground surfaces. International Research Journal of Engineering and Technology (IRJET), Vol. 6, Issue 6, p. 1974-1978.

[12]. Le Van Quynh, (2021). Dynamic analysis and control of cab mount system for construction machine, Science research topic: Thai Nguyen University, Thai Nguyen, Vietnam.