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Effect of Tire Stiffness on Wheel Loader Ride Comfort

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Abstract
Ride comfort of wheel loaders plays a vital role in ensuring operator safety, work efficiency, and long-term health. This study explores the impact of tire stiffness on ride comfort under varying operational loads using a half-machine dynamic model. The evaluation is based on the root mean square (RMS) values of vertical acceleration at the driver's seat (a_{ws}) and pitch angles of cab (a_{wc}), following the ISO 2631:1997(E) standards. The simulation results demonstrate that tire stiffness value significantly affect ride comfort when the machine operates under an ISO class E road surface at a speed of 5 km/h and full load. The outcomes offer a theoretical foundation for optimizing wheel loader tire parameters to maintain acceptable ride comfort during real-world operations.

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Keywords: Wheel Load, Acceleration Response, Tire Stiffness, Ride Comfort

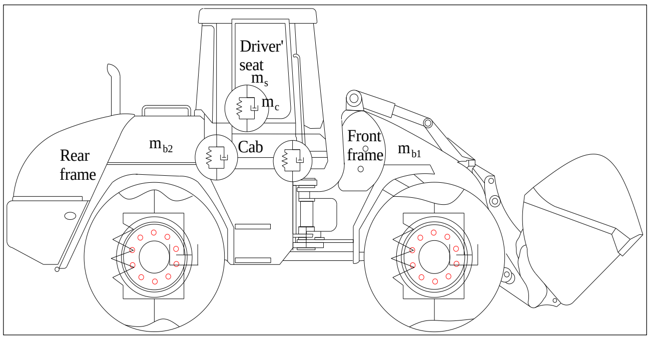
1. Introduction

Ride comfort is a crucial design consideration in off-road construction machinery, especially wheel loaders, due to their frequent operation on uneven terrains and under heavy load conditions. Poor ride comfort not only reduces operator efficiency but also leads to long-term health issues, particularly related to whole-body vibration (WBV). Therefore, evaluating and improving ride comfort has become a fundamental aspect in the optimization of vehicle suspension and tire systems. Tran Van Thoan *et al.* [1] conducted a comprehensive study on the efficiency of a driving wheel slip prevention system (DWSPS) for diesel engine trucks under poor pavement conditions, emphasizing the role of torque control and slip ratio reduction in improving vehicle acceleration performance. Similarlly, Tran Van Thoan *et al.* [2] proposed a PID-based control strategy for the driving wheel slip prevention system (DWSPS) in diesel engine dump trucks, emphasizing its effectiveness in improving traction under low-adhesion conditions and optimizing longitudinal vehicle dynamics. To Ngoc Thien and Bui Van Hai [3] conducted a study on the influence of cab isolation system damping coefficients on the ride comfort of vibratory rollers, utilizing a half-vehicle dynamic model to evaluate seat and cab responses under various excitation frequencies. Huan *et al.* [4] conducted a numerical study on the ride comfort performance of wheel loaders equipped with hydraulic isolation systems (HIS), highlighting the influence of orifice configurations and operating conditions on seat and cab vibration responses. Bui Van Cuong *et al.* [5] investigated the influence of cab suspension design parameters on the ride comfort of agricultural tractors using a half-vehicle dynamic model, highlighting the critical roles of stiffness and damping coefficients under ISO 2631-1997 evaluation standards. Le Van Quynh *et al.* [6] conducted a comparative study on the ride comfort of liquid-filled and rubber cab mount systems for vibratory rollers, demonstrating that liquid cab mounts (LCMs) significantly reduce RMS and PSD acceleration responses under varying operating conditions. Van Quynh Le *et al.* [7] conducted an optimization study on cab isolation systems for single drum vibratory rollers using a half-vehicle dynamic model and genetic algorithms. Their results demonstrated that the optimal design parameters significantly reduce vertical seat acceleration and cab pitch angle, enhancing ride comfort under ISO class D road conditions. Nguyen and Le [8] reviewed the research and development of cab isolation systems for off-road vibratory rollers, emphasizing that semi-active hydraulic mounts significantly enhance ride comfort by mitigating vibration transmitted from deformable terrains. Le Van Quynh *et al.* [9] conducted an experimental modal analysis and finite element simulation to optimize the cab's isolation system of a single drum vibratory roller, aiming to reduce low-frequency shaking in the forward direction by tuning the first-order natural frequency. Vanliem Nguyen *et al.* [10] developed a nonlinear dynamic model of an off-road vibratory roller to evaluate the low-frequency vibration performance of three different cab isolation mounts, revealing that hydraulic mounts significantly improve ride comfort compared to rubber and pneumatic ones. Jiao *et al.* [11] investigated the ride comfort performance of hydro-pneumatic isolation (HPI) systems for soil compactor cabs, demonstrating that high static stiffness and nonlinear damping effectively reduce low-frequency vibration and improve driver comfort under deformable terrain conditions. Le *et al.* [12] developed a nonlinear 3-DOF dynamic model of a single drum vibratory roller interacting with elastic-plastic soil, aiming to evaluate ride comfort under varying ground conditions by analyzing vertical excitation forces transmitted through the cab-seat isolation system. Quynh *et al.* [13] conducted a vibration analysis and optimal design study of cab isolation systems for vibratory rollers, focusing on mitigating low-frequency forward-direction shaking by introducing an auxiliary vibration isolator and optimizing system parameters through simulation. Le Van Quynh and Nguyen Khac Tuan [14] proposed an optimal design approach for cab isolation systems of vibratory rollers using an improved NSGA-II algorithm, demonstrating that multi-objective optimization significantly enhances ride comfort by reducing vertical, pitch, and roll vibrations under varying working conditions. Nguyen *et al.* [15] proposed a nonlinear dynamic model incorporating PID–Fuzzy control to enhance ride comfort of soil compactors, demonstrating that combined control strategies significantly reduce PSD and RMS acceleration responses of the seat and cab pitch under high-density elastoplastic soil conditions. Nguyen and Le [16] applied a machine learning approach (MLA) to optimize the control of vehicle isolation systems, demonstrating that MLA outperforms traditional fuzzy logic by significantly reducing vehicle acceleration and isolation system deformation under random road excitations. Tan *et al.* [17] developed a fuzzy self-tuning PID control strategy for semi-active cab isolation systems (SCIS) in wheel loaders, showing that the proposed method significantly improves ride comfort compared to passive systems under random road excitations. Quynh *et al.* [18] investigated the ride comfort improvement of earth-moving machinery using a semi-active hydraulic cab isolation system controlled by a fuzzy-PID algorithm, demonstrating its superior performance over passive systems under random ground excitations. Duy *et al.* [19] evaluated the ride comfort performance of a double-drum vibratory roller equipped with a semi-active hydraulic cab mount system, demonstrating that fuzzy logic control significantly reduces cab vibrations under varied operating conditions compared to passive mounting solutions. In this study, a half-vehicle dynamic model under different road conditions is established to analyze and evaluate the effects of design parameters on the wheel loader ride comfort. The design parameters of cab's isolation system such as stifness and damping coefficients are respectively analyzed based on two objective functions according to the international standard ISO 2631-1. This study examines the effects of tire stiffness on wheel loader ride comfort when the machine operates under an ISO class E road surface at a speed of 5 km/h and full load. A half-machine dynamic model is developed, and ride comfort is evaluated using the root mean square (RMS) values of vertical seat and cab pitch angle accelerations in accordance with ISO 2631:1997(E). Simulation results under full-load conditions and ISO class E road at 5 km/h reveal that tire stiffness has a significant impact on vibration levels transmitted to the driver. These findings offer a theoretical basis for the optimal design and parameter tuning of wheel loader tires to ensure acceptable ride comfort in real-world operations.

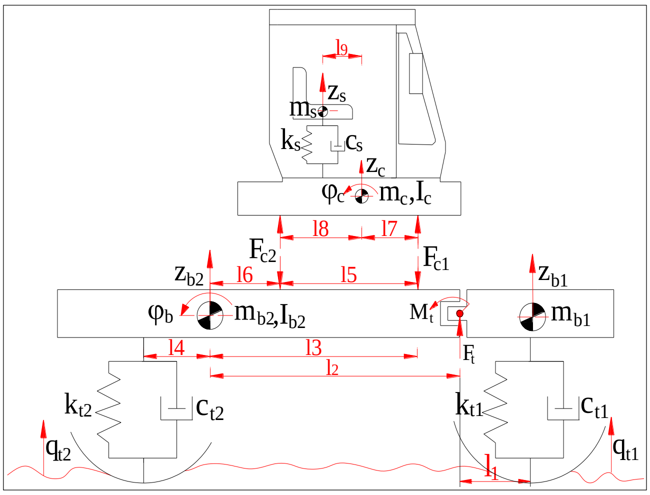
2. Machine Dynamic model

2.1 Half- machine Dynamic model [21, 23]

A half-machine dynamic model of wheel loader is developed based on reference [21, 23] 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 moments of 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 for determining 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)



(a) Structural diagram



(b) Half-machine dynamic model of a wheel loader

Fig 1: Structural diagram of a wheel loader

2.2 Equations of motion

The motion equations of m_{b2} 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

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

2.3 Gound surface excitations

In off-road applications, wheel loaders frequently encounter irregular ground surfaces characterized by large-amplitude and low-frequency excitations. To simulate these adverse road conditions, the present study employs an excitation model based on ISO 8608:2016 [21, 22, 23, 24], which describes the stochastic nature of road roughness through its spectral characteristics. The road input q(t) for the coupled vehicle–terrain dynamic interaction is generated using the following expression:

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

Here, $G_d(n_i)$ denotes the power spectral density (PSD) of the road surface at spatial frequency n_i corresponding to ISO roughness classes from A (smooth) to H (very rough). The term Δn_i represents the frequency bandwidth, while β_i is the randomly assigned phase angle within the interval [0, π], ensuring a realistic representation of random surface profiles.

3. Vehicle Ride Comfort Evaluation Criteria

To evaluate the ride comfort of the vehicle in the time domain, the approach outlined in ISO 2631-1:1997 [20, 25, 26, 27, 28, 29, 30] is adopted in this study. Specifically, the evaluation is based on the calculation of the frequency-weighted root mean square (r.m.s.) acceleration which reflects the cumulative effect of vibrations over a given measurement interval. The weighted acceleration response, denoted as

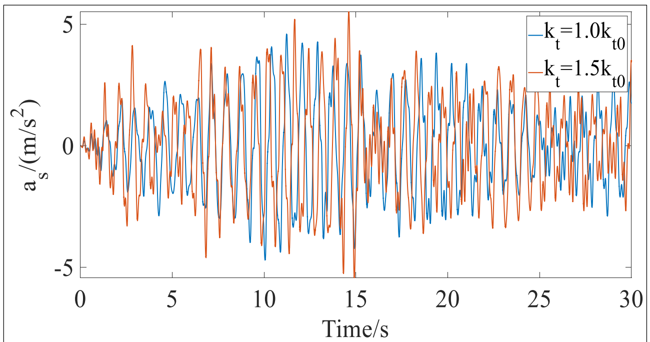
$$a_{wz} = \left[\frac{1}{T}\int_0^T a_z^2(t)dt\right]^{1/2} \tag{7}$$

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.

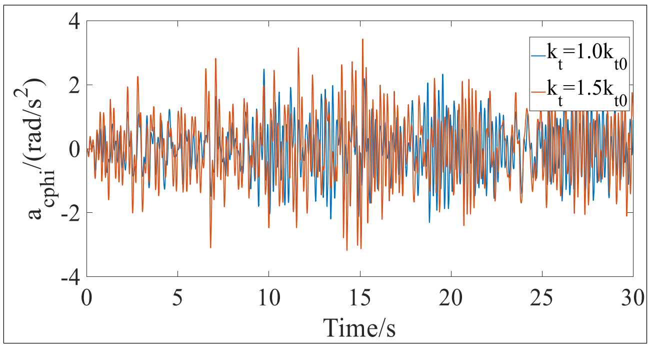
4. Results and Discussion

To evaluate the effects of tire stiffness on wheel loader ride comfort when the machine operates under an ISO class E road surface at a speed of 5 km/h and full load, the differential equations of motion of Fig.1 are simulated by the MATLAB/Simulink with design parameters in the Reference [23].

Increased tire stiffness: k_t=1.5 k_{t0} (k_{t0}=[k_{t1}, k_{t2}] is original tire stiffness of machine) is chosen to evaluate the effects of tire stiffness on wheel loader ride comfort. The evaluation results of acceleration responses of the vertical driver's seat (a_s) and cab's pitch angle (a_{cphi}) with k_t=1.5 k_{t0} compared to the k_t=1.0 k_{t0} case are shown Fig.2.



a) a_s

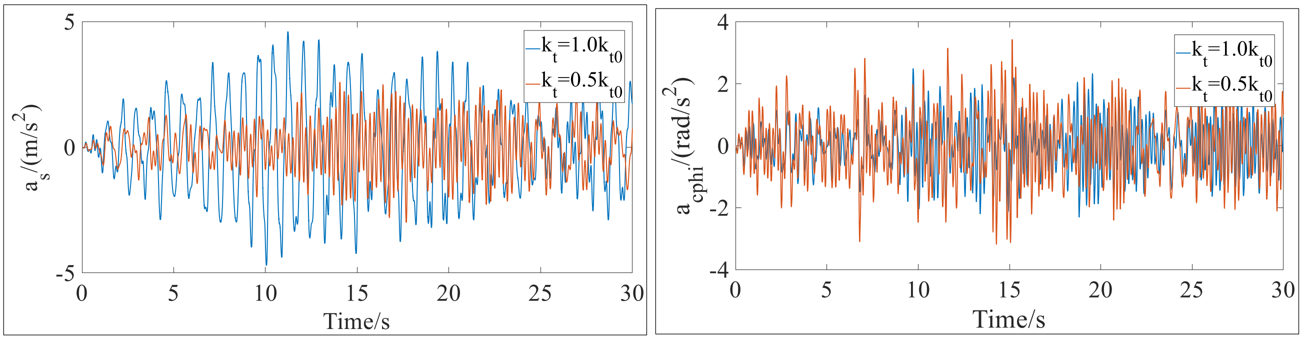


b) a_c

Fig 2: Acceleration responses of the vertical driver's seat (a_s) and cab's pitch angle (a_{cphi}) with k_t=1.5 k_{t0} compared to the k_t=1.0 k_{t0} case

From the results of Fig. 2, 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_{wcphi}) were calculated by Eq. (6) according to ISO 2631-1. The results indicate that the a_{ws} and a_{wc} values with k_t=1.5 k_{t0} condition increase by 5.48%, and 43.98%, respectively compared to the k_t=1.0 k_{t0} case. This results in a significant deterioration in the machine's ride comfort, primarily due to the increased pitch vibrations of the cab under higher tire stiffness conditions.

Reduced tire stiffness: k_t=0.5 k_{t0} is chosen to to evaluate the effects of tire stiffness on wheel loader ride comfort. The evaluation results of acceleration responses of the vertical driver's seat (a_s) and cab's pitch angle (a_{cphi}) with k_t=0.5 k_{t0} compared to the k_t=1.0 k_{t0} case are shown Fig.3.



a) a_s **b)** a_c

Fig 3: Acceleration responses of the vertical driver's seat (a_s) and cab's pitch angle (a_{cphi}) with k_t=0.5 k_{t0} compared to the k_t=1.0 k_{t0} case

The results of Fig. 3 indicate that the a_{ws} value with k_t=0.5 k_{t0} condition reduce by 57.68% compared to the k_t=0.5 k_{t0} case. This leads to a significant improvement in the machine's ride comfort under reduced tire stiffness. However, the pitch vibration of the cab increases by 17%.

4. Conclusions

In this study, the effects of tire stiffness on wheel loader ride comfort were evaluated using a half-machine dynamic model of wheel loader when the machine operates under an ISO class E road surface at a speed of 5 km/h and full load. The evaluation results have yielded the following conclusions: (i) the a_{ws} and a_{wc} values with m_{b1}=1.5 m_{b10} condition reduce by the a_{ws} and a_{wc} values with k_t=1.5 k_{t0} condition increase by 5.48%, and 43.98%, respectively compared to the k_t=1.0 k_{t0} condition. This leads to a significant deterioration in the machine's ride comfort, especially by increasing the pitch vibrations of the cab under increased tire stiffness; (ii) the a_{ws} value with k_t=0.5 k_{t0} condition reduce by 57.68% compared to the k_t=0.5 k_{t0} condition. This leads to a significant improvement in the machine's ride comfort under reduced tire stiffness. However, the pitch vibration of the cab increases by 17%. In future research, the team will focus on analyzing the influence of vehicle design parameters on the ride comfort of construction machinery.

5. Acknowledgment

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6. References

1. Thoan TV, Vu LA, Nguyen KV, Hai HH, Phuc HD, Khanh DN, *et al*. A survey of efficiency of wheel slip prevention controlled for diesel engine truck under poor pavement conditions. In: ICERA 2023. Lecture Notes in Networks and Systems, vol 943. Cham: Springer; 2024. p. 150-8. doi:10.1007/978-3-031-62238-0_16.
2. Van Thoan T, Vu L, Van Nguyen K, Hai H, Phuc DH, Khanh DN, *et al*. An investigation in the control effectiveness of the driving wheel slip prevention system of a diesel engine dump truck. SAE Int J Veh Dyn Stab NVH. 2024;8(3):311-27. doi:10.4271/10-08-03-0017.
3. Thien TN, Hai BV. Effects of cab isolation system damping coefficients on vibratory roller ride comfort. Int J Future Eng Innov. 2025;2(4):7-10. doi:10.54660/IJFEI.2025.2.4.07-10.
4. Huan CC, Ha DV, Vu LA, Thoan TV, Quynh LV. Ride comfort evaluation for a wheel loader with cab's hydraulic isolation system. In: ICERA 2022. Lecture Notes in Networks and Systems, vol 602. Cham: Springer; 2022. p. 846-54. doi:10.1007/978-3-031-19849-7_80.
5. Van Cuong B, Huan CC, Van Quynh L, Binh DT. Effects of design parameters of cab's suspension system on an agricultural tractor ride comfort. In: ICERA 2022. Lecture Notes in Networks and Systems, vol 602. Cham: Springer; 2023. doi:10.1007/978-3-031-22200-9_93.
6. Van Quynh L, Vu LA, Van Cuong B, Tan HA, Long LX. A comparative analysis of ride performance of double-drum vibratory roller with two cab mount systems. In: ICERA 2021. Lecture Notes in Networks and Systems, vol 366. Cham: Springer; 2022. p. 29-40. doi:10.1007/978-3-030-92574-1_3.
7. Van Quynh L, Duy NT, Van Liem N, Van Cuong B, Long LX. Optimal design of cab's isolation system for a single-drum vibratory roller. In: ICERA 2020. Lecture Notes in Networks and Systems, vol 178. Cham: Springer; 2021. p. 759-68. doi:10.1007/978-3-030-64719-3_68.
8. Nguyen V, Le V. Development of cab isolation systems of off-road vibratory rollers: review research. Math Models Eng. 2020;6(2):93-102. doi:10.21595/mme.2020.21241.
9. Quynh LV, Jianrun Z, Liem NV, Cuong BV, Long LX, Phuong DT. Experimental modal analysis and optimal design of cab's isolation system for a single drum vibratory roller. Vibroengineering PROCEDIA. 2020;31:52-6. doi:10.21595/vp.2020.21325.
10. Nguyen V, Zhang J, Le V, Jiao R. Vibration analysis and modeling of an off-road vibratory roller equipped with three different cab's isolation mounts. Shock Vib. 2018;2018:8527574. doi:10.1155/2018/8527574.
11. Jiao R, Nguyen V, Le V. Ride comfort performance of hydro pneumatic isolation for soil compactors cab in low frequency region. J Vibroeng. 2020;22(5):1174-86. doi:10.21595/jve.2020.21345.
12. Le VQ, Zhang J, Liu X, Wang Y, Thoan PV. Ride comfort evaluation of vibratory roller under different soil ground. Trans Chin Soc Agric Eng. 2013;29(9):39-47.
13. Quynh L, Zhang J, Jiao G, Liu X, Wang Y. Vibration analysis and optimal design for cab's isolation system of vibratory roller. Adv Mater Res. 2011;199-200:926-30. doi:10.4028/www.scientific.net/AMR.199-200.926.
14. Quynh LV, Tuan NK. Optimal design parameters of cab's isolation system for vibratory roller using a multi-objective genetic algorithm. Appl Mech Mater. 2018;875:105-12. doi:10.4028/www.scientific.net/AMM.875.105.
15. Nguyen V, Jiao R, Le V, Hoang A. Performance of PID-Fuzzy control for cab isolation mounts of soil

compactors. Math Models Eng. 2019;5(4):137-45. doi:10.21595/mme.2019.21213.
16. Nguyen V, Le V. Application of machine learning approach for controlling the vehicle isolation system. In: Xu JY, editor. Mechatronics and Automation Technology. Amsterdam: IOS Press; 2024. p. 262. doi:10.3233/ATDE231113.
17. Tan HA, Cuong BV, Tan ND, Chau NM, Huan CC. Improvement of ride quality for a wheel loader with semi-active cab isolation system via fuzzy self tuning of PID controller. J Mil Sci Technol. 2023;(FEE):197-203. doi:10.54939/1859-1043.j.mst.FEE.2023.197-203.
18. Quynh LV, Ha DV, Cuong BV, Vu LA, Thoan TV. Improvement of ride comfort quality for an earth-moving machinery with semi-active cab isolation system. E3S Web Conf. 2021;304:02012. doi:10.1051/e3sconf/202130402012.
19. Duy NT, Quynh LV, Ha DV, Cuong BV, Long LX. Ride comfort evaluation for a double-drum vibratory roller with semi-active hydraulic cab mount system. E3S Web Conf. 2021;304:01008.
20. doi:10.1051/e3sconf/202130401008.
21. International Organization for Standardization. Mechanical vibration and shock-evaluation of human exposure to whole-body vibration, part I: general requirements. ISO 2631-1. Geneva: ISO; 1997.
22. Canh CH, Nguyen DT, Nguyen VM, Pham MT, Nguyen TH, Dam HV. Analysis of the influence of road surface conditions on wheel loader ride comfort. Int J Eng Invent. 2025;14(3):189-93.
23. International Organization for Standardization. Mechanical vibration—road surface profiles—reporting of measured data. ISO 8608. Geneva: ISO; 1995.
24. Tran TQ. Study on the ride effectiveness of hydraulic isolation system for construction machine cab [master's thesis]. Thai Nguyen: Thai Nguyen University of Technology; 2022.
25. Le VQ, Thao VTP. Effect of operating conditions on vehicle ride comfort and road surface friendliness with air suspension system. Int Res J Eng Technol. 2020;7(6):7671-5.
26. Long LX, Quynh LV, Cuong BV. Study on the influence of bus suspension parameters on ride comfort. Vibroengineering PROCEDIA. 2018;21:77-82. doi:10.21595/vp.2018.20271.
27. Quynh LV, Thao VTP, *et al*. Influence of design parameters of cab's isolation system on vibratory roller ride comfort under the deformed ground surfaces. Int Res J Eng Technol. 2019;6(6):1974-8.
28. Wang X, Liem NV, Li S, Quynh LV. Research and optimisation of the dynamic parameters of the QZSS embedded in the seat suspension system of the vehicles. Veh Syst Model Test. 2023;17(1):81-99. doi:10.1504/IJVSMT.2023.132323.
29. Van Cuong B, Huan CC, Van Quynh L, Binh DT. Effects of design parameters of cab's suspension system on an agricultural tractor ride comfort. In: ICERA 2022. Lecture Notes in Networks and Systems, vol 602. Cham: Springer; 2023. doi:10.1007/978-3-031-22200-9_93.
30. Le Xuan L, Dang Viet H, Le Van Q, Bui Van C, Vu Thanh N. Effect of operating conditions on a heavy truck ride comfort with hydro-pneumatic suspension system. E3S Web Conf. 2021;304:02011. doi:10.1051/e3sconf/202130402011.
31. Tan HA, Van Thoan P, Tan ND, Hien VT, Van Quynh L. Ride performance analysis of a semi-active hydraulic engine mounting system of a passenger car. In: ICERA 2023. Lecture Notes in Networks and Systems, vol 944. Cham: Springer; 2024. doi:10.1007/978-3-031-62235-9_33