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Effect of Design Parameters of Cab's Isolation System on a Wheel Loader Ride Comfort

Vu Ngoc Quynh, Canh Chi Huan, Nguyen Tien Han

***Abstract*— The ride comfort of the wheel loader is one of the important indicators to evaluate the quality of construction machinery. To evaluate the wheel loader ride comfort, a half-vehicle dynamic model 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. The obtaine results indicate that the effects of the stiffness and damping parameters of cab's isolation system on vehicle ride comfort are obvious. In addition, the results of the study are the theoretical basis for optimizing the design parameters of cab's isolation system to improve the wheel loader ride comfort.**

***Index Terms*—Wheel load, cab, isolation system, ride comfort.**

I. INTRODUCTION

A wheel loader is a type of construction machine that is not equipped with a suspension system to elastically connect the axle and the chassis, resulting in vibration sources being transmitted to driver's human body through cab's isolation sytem, and driver's seat suspension system. Therefore, analyzing the influence of design parameters of cab's isolation is one of the important issues to complete their design. X. Li, et al, (2017) [1] analyzed the damping effect of different layouts of suspensions of a traditional wheel loader such as unconnected strut (UCS), interconnected in roll plane (IC-R) and interconnected in roll and pitch plane (IC-RP) on vehicle ride comfort and driving and operation stability. Le Van Quynh, et al, (2019) [2] analyzed the design parameters of cab's isolation system such as the stiffness and damping coefficients to work out their effects on vehicle ride comfort using the 3D nonlinear dynamic model of a single drum vibratory roller using the nonlinear geometric characteristics of wheel-deformation of soil ground contact. Doan Thanh Binh, et al, (2021) [3] analyzed the effects of parameters of cab's isolation system on ride comfort for a single-drum vibratory roller using a half vehicle dynamic model. Huan, C.C., et al, (2022) [4] proposed a half-vehicle dynamic model of a wheel loader to to evaluate a wheel loader ride comfort using hydraulic isolation system (HIS) of cab with the orifice and the annular orifice. Van Cuong, B., et al, (2023) [5] proposed a half-vehicle dynamic model of an agricultural tractor to analyze the effect of the design parameters of cab's suspension system on an agricultural tractor vehicle ride comfort. Vanliem Nguyen, et al, (2018) [6] proposed a dynamic model of the vibratory roller interacting with the off-road deformed terrain to analyze the low-frequency performance of three different cab's isolation system on vehicle ride comfort. Renqiang Jiao, et al, (2020) [7] proposed a nonlinear dynamic model of the soil compactor interacting with the deformable terrains to analyze the low frequency ride comfort of cab's hydro pneumatic isolation (HPI). Nguyen Dinh Tan, et al, (2018) [8] analyzed an overview of research on ride comfort characteristics of cab's isolation systems of construction machines. In addition, some research results on the influence of suspension design parameters from traditional vehicles to electric vehicles on vehicle ride comfort [9], [10], [11]. To improve the ride comforrt effectiveness of cab's isolation system of construction machines, optimization and control solutions for the system are proposed by scientists. L. V. Quynh, et al, (2011) [12] analyzed cab's low-frequency sloshing analysis and found out the optimal design for cab's isolation system of vibratory roller using finite element method. Le, Van Quynh and Nguyen Khac Tuan, (2018) [13] proposed 3D nonlinear dynamic model of a single drum vibratory roller to optimize the design parameters of cab's isolation system using NSGA-II algorithm when vehicle operates under the different conditions. L. V. Quynh, et, al, (2020) [14] proposed a half-vehicle ride dynamic mode to find out the optimal design parameters for drum's isolation systems of a double drum vibrating roller using the genetic algorithm (GA). Another study, the optimal design of cab's isolation system for a single drum vibratory roller was found using the finite element method [15]. Similarly, Van Quynh, L., et al (2021) [16] proposed a half-vehicle ride dynamic model of a single drum vibratory roller to find out the optimal design parameters of cab's isolation systems using the genetic algorithm (GA). Van Quynh, L., et al (2021) [17] proposed a Fuzzy –PID controller to control of the damping coefficient of a semi-active hydraulic cab isolation system (SHCIs) for an earth-moving machinery. Hoang Anh Tan, et al, (2023) [18] proposed a fuzzy self-tuning of PID controller to control the damping coefficient of Semi-active cab isolation system (SCIS) for a wheel loader. In addition, some research results on improving the ride comfort of other vehicles are presented in the literatures [19], [20], [21], [22], [23]. 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.

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II. DYNAMIC MODEL OF WHEEL LOADER

A. *Half-Vehicle Dynamic Model [1]*

A half-vehicle dynamic model of wheel loader is developed based on reference [18], [26] 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).

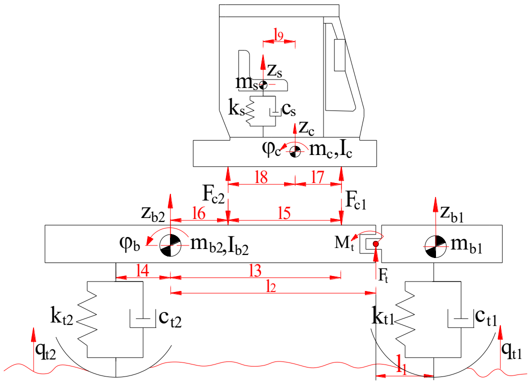


Figure.1: Half-vehicle dynamic model of a wheel loader

B. *Equation of motion [1]*

The equations of vehicle motion can be formulated in different ways such as Lagrange's equation, Newton-Euler equation, Jourdain's principle. In this study, Newton-Euler equation is chosen to describe the equations of vertical motion of electric vehicle. From half-vehicle dynamic model of a wheel loader in Fig. 1, the dynamic equations of a wheel loader are written as follows:

$$\begin{cases} m_s\ddot{z}_s = -F_s \\ m_c\ddot{z}_c = F_s - \sum_{i=1}^{i=2} F_{ci} \\ I_c\ddot{\varphi}_c = \sum_{i=1}^{i=2} (-1)^{i+1} F_{ci} l_{i+5} - F_s l_8 \\ m_{b2}\ddot{z}_{b2} = \sum_{i=1}^{i=2} F_{ci} - F_{t2} + F_t \\ I_c\ddot{\varphi} = F_{t2} l_3 - F_t l_2 - \sum_{i=1}^{i=2} F_{ci} l_{i+3} - M_t \end{cases} \qquad (1)$$

C. *Input excitation [26]*

Road surface excitation function: Surface roughness plays an important role in evaluating the dynamic interaction between vehicles and road. It is simulated in space domain and acts as an input to the vehicle-road model. The road surface roughness irregularities can be represented with a normal stationary argotic random process described by its Power Spectral Density (PSD). According to the International Standards Organization (ISO) 8608 [11], PSD of road roughness can be defined as Eq. (2):

$$G_q(n) = G_q(n_0)\left(\frac{n}{n_0}\right)^{-w} \qquad (2)$$

where, n is spatial frequency in m^{-1}, n_0 is reference spatial frequency with a value of $0.1m^{-1}$, $G_q(n_0)$ is PSD value for reference spatial frequency in m^3, w is termed waviness, and reflects approximate frequency structure of the road profile, commonly taken as w=2. The classification of road roughness is based on the index of International Organization for Standardization ISO 8608. The ISO has proposed road roughness classification from class A - very good to class H - very poor, according to different values of $G_q(n_0)$. The road profile is generated as the sum of a series of harmonics:

$$q(t) = \sum_{k=1}^{N} \sqrt{2G_q(n_k)\Delta n}\cos(2\pi n_k t + \phi_k) \qquad (3)$$

ϕ_k is the random phase uniformly distributed from 0 to2π; $G_q(n_k)$ is the power spectral density (PSD) function (m^3/cycle) for the road surface elevation; n_k is the wave number (cycle/m).

III. VEHICLE RIDE COMFORT EVALUATION CRITERIA

The time-domain method can be applied to evaluate the vehicle ride comfort accordingtoISO2631-1 (1997) [24], 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

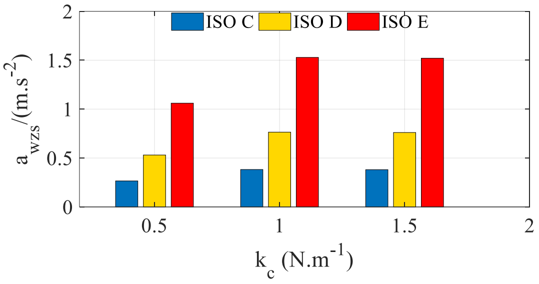
$$a_{wzs} = \left[\frac{1}{T}\int_0^T a_{zs}^2(t)dt\right]^{1/2} \qquad (2)$$

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

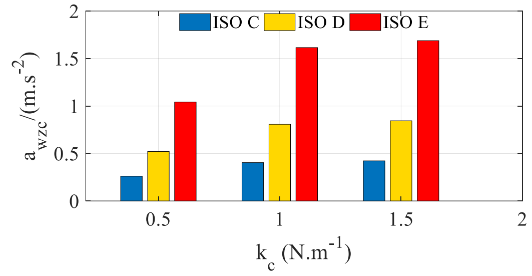
IV. SIMULATION AND DISCUSSION

To analyze the effects of stiffness and damping coefficient parameters of the cab vibration isolation system on a wheel loader ride comfort, Matlab/Simulink software is used to solve Eq. (1) when vehicle moves on the road surfaces from ISO class C to ISO class E at a speed of 5 km/h and full load.

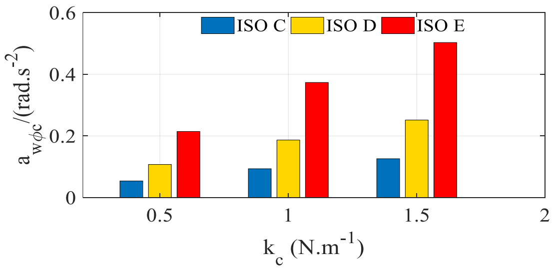
Effects of stiffness coefficients, k_c: To evaluate the effects of k_{ci} on a wheel load ride comfort, the k_{ci} values as k_c= [0.5 1.0 1.5]x k_{c0} (where, k_{c0} = [k_{c1}, k_{c2}] represents the original values). The values of a_{wzs}, a_{wzc}, and $a_{w\varphi c}$ various values of k_c are illustrated in Fig. 2. From the obtained results of Fig.2, it could be seen that the values of a_{wzs}, a_{wzc}, and $a_{w\varphi c}$ significantly increase as the k_{ci} values increase which means the ride comfort of the machine will decrease. In addition, the values of a_{wzs}, a_{wzc}, and $a_{w\varphi c}$ significantly increase when the road surface becomes bad which means the vehicle ride comfort also deteriorates, when the road surface conditions deteriorate. However, improving the comfort is based on the reasonable design of cab's isolation system.



(a) a_{wzs} values



(b) a_{wzc} values



(c) $a_{w\varphi c}$ values

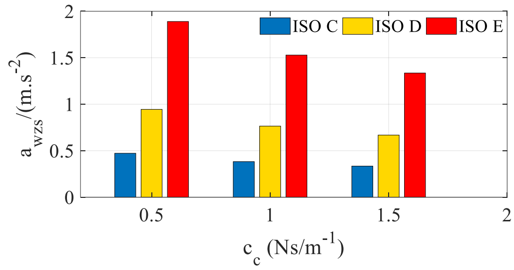
Figure 2: values of a_{wzs}, a_{wzc}, and $a_{w\varphi c}$ various values of k_c

Effects of damping coefficients, c_c: To evaluate the effects of k_{ci} on a wheel load ride comfort, the k_{ci} values as c_c= [0.5 1.0 1.5]x c_{c0} (where, c_{c0} = [k_{c1}, k_{c2}] represents the original values). The values of a_{wzs}, a_{wzc}, and $a_{w\varphi c}$ various values of c_c are illustrated in Fig. 3. From the obtained results of Fig. 3, it could be seen that the values of a_{wzs}, a_{wzc}, and $a_{w\varphi c}$ significantly reduce as the c_c values increase which means the vehicle ride comfort significantly improve. In addition, the values of a_{wzs}, a_{wzc}, and $a_{w\varphi c}$ significantly increase when the road surface becomes bad which means the vehicle ride comfort also deteriorates, when the road surface conditions deteriorate.

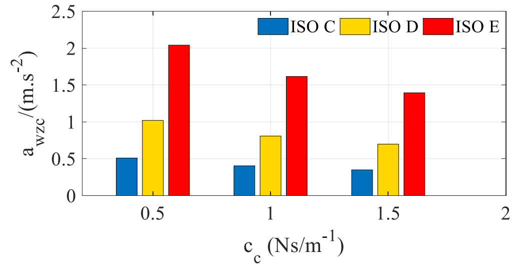
V. Conclusion

In this study, to analyze and evaluate the effects of design parameters on the wheel loader ride comfort, a half-vehicle dynamic model under different road conditions was established based on reference [26]. The major conclusions can be drawn from the analysis results as follows:

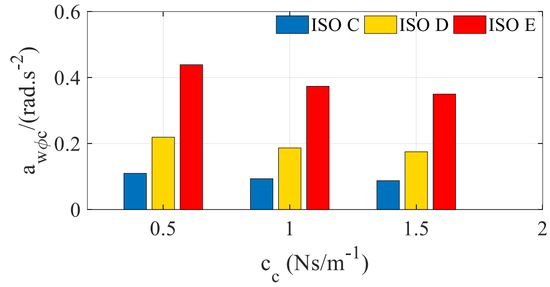
i) The values of a_{wzs}, a_{wzc}, and $a_{w\varphi c}$ significantly increases ad the k_{ci} values increased which means the ride comfort of the machine will decrease when vehicle moves on the road surfaces from ISO class C to ISO class E at a speed of 5 km/h and full load. In addition, the values of a_{wzs}, a_{wzc}, and $a_{w\varphi c}$ significantly increase when the road surface becomes bad which means the vehicle ride comfort also deteriorates, when the road surface conditions deteriorate.



(a) a_{wzs} values



(b) a_{wzc} values



(c) $a_{w\varphi c}$ values

Figure 3: values of a_{wzs}, a_{wzc}, and $a_{w\varphi c}$ various values of c_c

ii) a_{wzs}, a_{wzc}, and $a_{w\varphi c}$ values significantly reduce as the c_c values increase which means the vehicle ride comfort significantly improve when vehicle moves on the road surfaces from ISO class C to ISO class E at a speed of 5 km/h and full load.

iii) The values of a with increasing k decrease significantly when the vehicle moves on bad road surfaces, so the problem of improving the damping coefficients is an important issue for designers to improve the structure of cab's isolation system of construction machinery.

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