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Influence of the Design Parameters of Cab Suspension System on Vehicle Ride Comfort

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ABSTRACT

The purpose of this research is to analyze the influence of design parameters of cab suspension system on vehicle ride comfort. A three-dimensional nonlinear dynamic model of heavy truck with 15 degrees of freedom (DOF) is established for simulation and analysis. The weighted root mean square (RMS) acceleration responses of the cab according to ISO 2631-1(1997) are chosen as objective functions which uses Matlab/Simulink software to simulate and analyze the objective functions. The influence of the design parameters of cab suspension system on vehicle ride comfort which include the stiffness and damping coefficients of cab suspension system are analyzed in this paper. The results show that the best combination of between the stiffness and damping coefficients of cab suspension system on the vehicle ride comfort is very important for optimal suspension design. The values of the stiffness and damping coefficients of cab suspension system are within achieved the value ranges (0.75k0≤ k≤ k0) and (1.25c0≤ c≤1.5c0) to improve the cab ride comfort.

KEYWORDS: Heavy truck, Cab suspension system, Vehicle dynamic model, ride comfort, stiffness coefficient, damping coefficient.

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1. INTRODUCTION

The cab suspension system is one of the important components to connect the cab and its vehicle body which not only affects the comfort of the vehicle, but also has a negative impact on the safety of driving. To improve vehicle ride comfort optimization and matching of cab suspension parameters is important. A fuzzy logic controller was used to control the semi-active isolation systems of the heavy truck under two types of step and random road surfaces and truck ride comfort was improved by using the cab controlled [1]. The ride comfort of vehicle using a hydro-pneumatic suspension applied with the semi-active control was analyzed and compared with a passive cab suspension [2]. The effects of vehicle suspension parameters on ride comfort based on the full-vehicle vibration model were studied in the references [3], [4]. The cab's low-frequency shaking for a single drum vibratory roller was researched by using single point excitation and multi-point measurement method and the modal analysis theory to analyze the natural frequencies of vehicle [5]. The method for the optimized design of the vehicle suspension system was applied to improve vehicle ride comfort [6]. In this paper, in order to evaluate the influence of design parameters of cab suspension system on vehicle ride comfort, a three dimensional nonlinear dynamic model with 15 DOF is used to simulate and analyze. Matlab/Simulink software is used to simulate the vehicle dynamic model with the random road surface roughness according to the international standard ISO 8068 [7]. The design parameters of cab suspension system such as stiffness and damping coefficients are analyzed based on the weighted rms acceleration responses of gravity of cab according to the international standard ISO 2631-1(1997) [8].

2. FULL VEHICLE DYNAMIC MODEL

The heavy truck with the rubber spring suspension system [9] is selected for simulating and analyzing the influence of design parameters of cab suspension system on vehicle ride comfort, as shown in Fig. 1. In Fig.1: k_i, k_{41}, k_{42}, k_{51}, k_{52}, k_{61}, k_{62}, k_7, k_8 are the stiffness coefficients of rubber spring suspension system of vehicle and cab suspension systems, respectively; c_i, c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8 are the damping coefficients of tire, vehicle and cab suspension systems, respectively; l_{01}, l_{04}, l_{42}, l_{43},… are the distances; m_1, m_3, m_5,… are the mass; I_2, I_4, I_6, I_8, I_{10} I_{14}, I_{15} are the moments of inertia of the mass.
The general dynamic differential equation for the three axle heavy truck is given by the following matrix form:

$$[M]\{\ddot{z}\} + [C]\{\dot{z}\} + [K]\{z\} = [C_t]\{\dot{q}\} + [K_t]\{q\} \quad (1)$$

where [M] is the mass matrix; [C] is the damping matrix of the suspension system; [K] is the stiffness matrix of the suspension system; $[C_t]$ is the damping matrix of the wheel system; $[K_t]$ is the stiffness matrix of the wheel system; {z} is the vector of displacement; {q} is the vector of excitation of road surface.

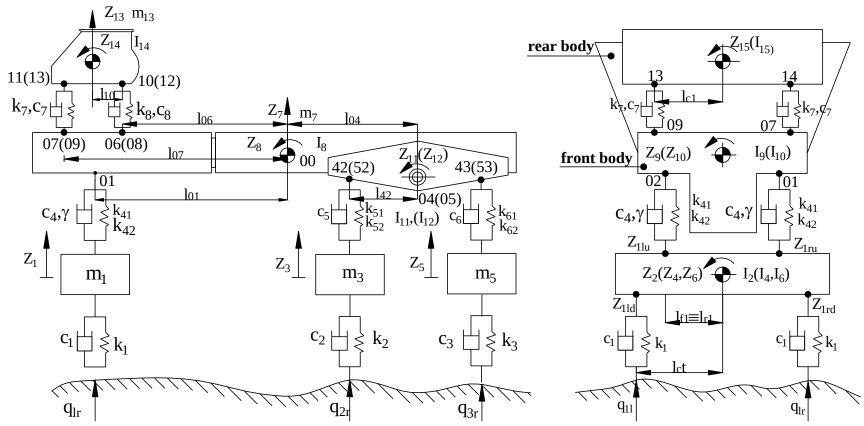


Fig.1. Three dimensional dynamic model of the heavy truck [9]

3. ROAD SURFACE ROUGHNESS

Road surface roughness plays an important role in analyzing driver ride comfort. The random excitation of road surface roughness can be represented with a periodic modulated random process. The general form of the displacement PSD of the road surface roughness is determined by the experimental formula [10]:

$$S_q(n) = S_q(n_0)\left(\frac{n}{n_0}\right)^{-\omega} \quad (2)$$

where space frequency n is the reciprocal of the wavelength λ. It means wave numbers in a meter. n_0 is reference space frequency, it's defined as 0.1m^{-1}. $S_q(n)$ is PSD of road surface under the reference space frequency $S_q(n_0)$ known as the road surface roughness coefficient and ω is the frequency index which decides the frequency configuration of PSD of road surface $(\omega = 2)$. The road surface roughness is assumed to be a zero-mean stationary Gaussian random process. It can be generated through an inverse Fourier transformation:

$$q(t) = \sum_{i=1}^{N} \sqrt{2 S_q(n_i)\Delta n}\, \cos(2\pi n_k t + \phi_i) \quad (3)$$

where, ϕ_i is random phase uniformly distributed from 0 to 2π.

In this study, typical road surface roughness is adopted according to the standard ISO 8068[7] and computer simulation result of the typical road surface roughness ISO 8068 level B is shown in Fig.2.

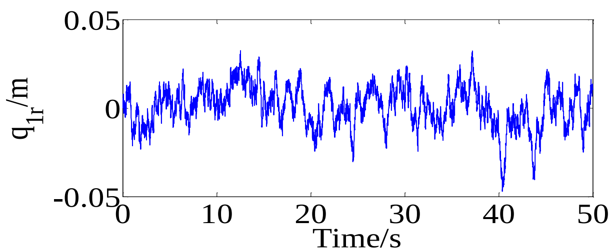


Fig. 2. Road surface roughness according to the standard ISO 8068 level D

4. VEHICLE RIDE COMFORT EVALUATION METHOD

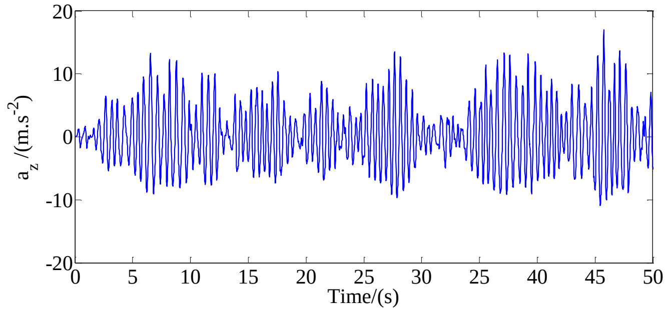
In this study, in order to analyze the influence of cab suspension parameters on ride comfort, the rms vertical acceleration, pitch angle and roll angle acceleration of the cab according to ISO 2631-1(1997) are chosen as objective functions. Vibration evaluation based on the basic evaluation method always includes measurements of the weighted root-mean-square (rms) acceleration is defined by:

$$a_w = \left[\frac{1}{T} \int_0^T a_w^2(t)\,dt \right]^{1/2} \quad (4)$$

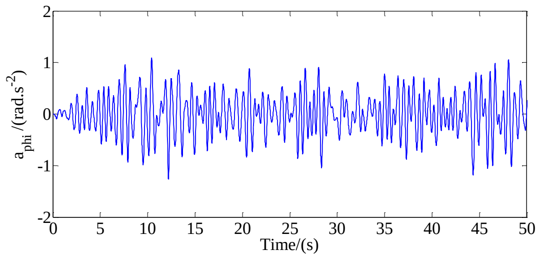
where, $a_w(t)$ is the weighted acceleration (translational and rotational) as a function of time, m/s^2; T is the duration of the measurement,s.

5. SIMULATION AND ANALYSIS RESULTS

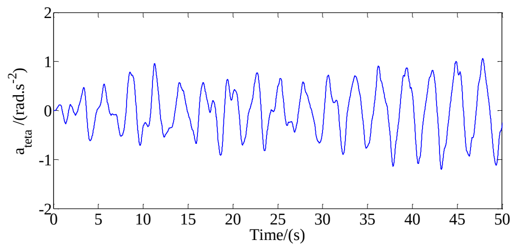
To evaluate the influence of the influence of design parameters of cab suspension system on vehicle ride comfort, Matlab/Simulink software is used to simulate with a specific set of parameters of heavy truck [9] with random input of the road surface roughness. The simulation results of the vertical acceleration, pitch angle and roll angle acceleration of cab while vehicle moves on the ISO level D road surface at v=30 km/h and fully loaded, is shown in Fig.3.



a) The vertical acceleration at the center of gravity of cab (a_z)



b) The pitch angle acceleration at the center of gravity of cab (a_{phi})



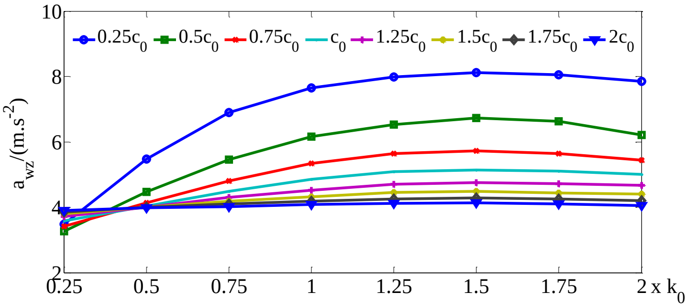
c) The roll angle acceleration at the center of gravity of cab (a_{teta})

Fig.3. The acceleration responses at the center of the gravity of cab when vehicle moves on the ISO level D road surface at v=30 km/h

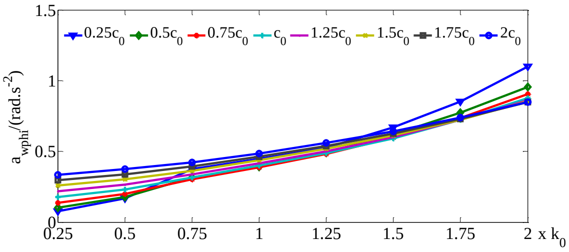
From results of Fig.3 can be determined the values of the vertical, pitch angle and roll angle weighted rms acceleration of gravity of cab, respectively a_{wz}=4.85 m.s^{-2}, a_{wphi}=0.399 rad.s^{-2} and a_{wteta}=0.504 rad.s^{-2}. Both stiffness and damping coefficients of cab suspension system have a large influence on vehicle ride comfort. In order to analyze the influence of cab suspension parameters such as stiffness and damping coefficients on ride comfort that will be continued to discuss in the next sections.

5.1. Influence of stiffness coefficients of cab suspension system

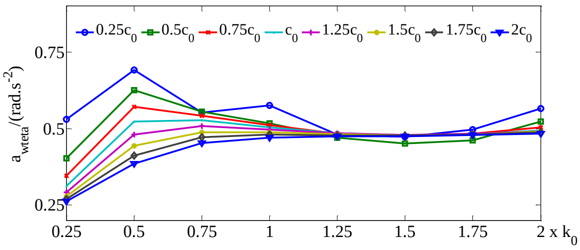
In order to analyze the influence of stiffness coefficients of cab suspension system on vehicle ride comfort, the values of stiffness coefficients of cab suspension system k=[0.25 0.5 0.75 1 1.25 1.5 1.75 2.0]xk_0, where $k_0=[k_{7r}, k_{7l}, k_{8r}, k_{8l}]^T$ and the values of damping coefficients of cab suspension system c=[0.25 0.5 0.75 1 1.25 1.5 1.75 2.0]xc_0, where $c_0=[c_{7r}, c_{7l}, c_{8r}, c_{8l}]^T$ were analyzed when vehicle moves on the ISO level D road surface at v=30 km/h and fully loaded. Denote the vehicle stiffness and damping coefficients in the reference document [9] such as k_0 and c_0. The influence of stiffness coefficients of cab suspension system on the values a_{wz}, a_{wphi} and a_{wteta} values are shown in Fig.4. From Fig.4 shows that the values of stiffness coefficient increase, the values of a_{wz}, a_{wphi} and a_{wteta} tend to increase that makes the negative effects on cab ride comfort as well as vehicle ride comfort. The a_{wz} values increase quickly when the values of the damping coefficients are c=0.25c_0 and c=0.5c_0 and do not change much when the damping coefficient increases from 0.5c_0 to 2c_0. When the stiffness coefficient increases from 1.5k_0 to 2k_0 the values a_w decrease slightly. The values a_{wphi} increase quickly when the stiffness coefficient increases. The values a_{wteta} increase when the stiffness coefficient increases from $0.25k_0$ to $0.5k_0$ and do not change much when the stiffness coefficient increases from $0.5k_0$ to $2k_0$.



a) The vertical acceleration values at the center of gravity of cab (a_{wz})



b) The pitch angle acceleration values at the center of gravity of cab (a_{wphi})

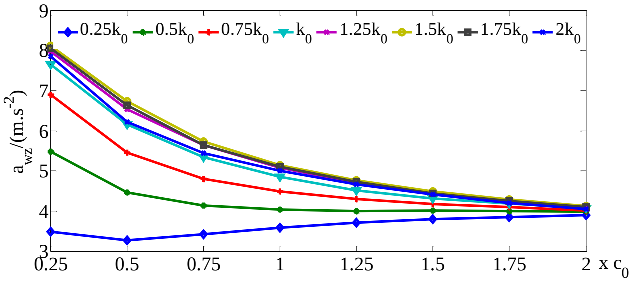


c) The roll angle acceleration values at the center of gravity of cab (a_{wteta})

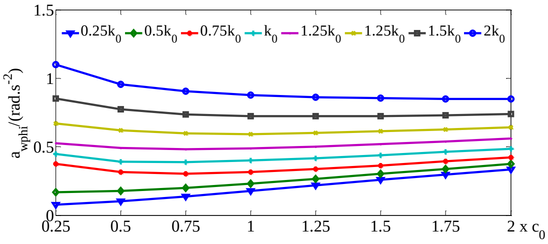
Fig.4. Influence of cab suspension stiffness coefficients on ride comfort

5.2. Influence of damping coefficients of cab suspension system

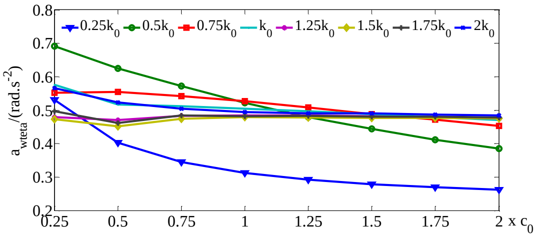
To evaluate the influence of damping coefficients of cab suspension system on vehicle ride comfort, the values of the values of damping coefficients of cab suspension system c=[0.25 0.5 0.75 1 1.25 1.5 1.75 2.0]xc_0, where $c_0=[c_{7r}, c_{7l}, c_{8r}, c_{8l}]^T$ and the values of stiffness coefficients of cab suspension system. k=[0.25 0.5 0.75 1 1.25 1.5 1.75 2.0]xk_0, where $k_0=[k_{7r}, k_{7l}, k_{8r}, k_{8l}]^T$ were chosen to simulate and analyze when vehicle moves on the ISO level D road surface at v=30 km/h and fully loaded. The influence of damping coefficients of cab suspension system on vehicle ride comfort on the a_{wz}, a_{wphi} and a_{wteta} values are shown in Fig.5. From the results in Fig.5 shows that the values of damping coefficient of cab suspension system form $0.25c_0$ to c_0 increases, the values a_{wz} and a_{wteta} tend to decrease and the a_{wphi} values do not change much which makes vehicle ride comfort considerably improved. When the value of the damping and stiffness coefficient increases from $1.5c_0$ to $2c_0$ and from $1.5k_0$ to $2k_0$ the a_{wz}, and a_{wteta} values decrease about from 1.76% to 2.83% that make the ride comfort of cab. From the results of Fig.4 and Fig.5, the values of the stiffness and damping coefficients of cab suspension system are within the value ranges ($0.75k_0 \leq k \leq k_0$) and ($1.25c_0 \leq c \leq 1.5c_0$).



a) The vertical acceleration values at the center of gravity of cab (a_{wz})



b) The pitch angle acceleration values at the center of gravity of cab (a_{wphi})



c) The roll angle acceleration values at the center of gravity of cab (a_{wteta})

Fig.5. Influence of cab suspension damping coefficient on ride comfort

6. CONCLUSION

In this paper, in order to analyze design parameters of cab suspension system on vehicle ride comfort, a 3D dynamic model is developed for simulating and evaluating. The major conclusions that can be drawn from the evaluation results as follows: (i) The reasonable matching of stiffness and damping coefficients can efficiently improve ride comfort, which keeping ride comfort within a safety limits and ensuring the safety of the road surface and (ii) The values of the stiffness and damping coefficients of cab suspension system are within the value ranges ($0.75k_0 \leq k \leq k_0$) and ($1.25c_0 \leq c \leq 1.5c_0$).

7. REFERENCES

[1]. Nguyen Van Liem, Le Van Quynh, Ride comfort performance of heavy truck with three control cases of semi-active isolation systems, Vibroengineering Procedia, Vol. 22, 2019, p. 93-98.

[2]. KyuhyunSim et al, Effectiveness evaluation of hydro-pneumatic and semi-active cab suspension for the improvement of ride comfort of agricultural tractors, Journal of Terramechanics, Vol. 69, February 2017, p. 23-32

[3]. Le Xuan Long et al, Study on the influence of bus suspension parameters on ride comfort, Vibroengineering Procedia, Vol. 21, 2018, p. 77-82.

[4]. Le Van Quynh et al, Effects of Suspension Design Parameters of a Semi-trailer Truck on Vehicle Ride Comfort and Road Surface Friendliness, International Conference on Engineering Research and Applications ICERA 2019: Advances in Engineering Research and Application p. 281 -289.

[5]. Le Van Quynh et al, Experimental modal analysis and optimal design of cab's isolation system for a single drum vibratory roller, Vibroengineering Procedia, May 2020, Vol.31, p.52-56.

[6]. Abolfazl Seifi et al, Optimum design for passive suspension system of a vehicle to prevent rollover and improve ride comfort under random road excitations, Proc IMechE Part K: J Multi-body Dynamics, 2015, p.1-16.

[7]. Mechanical vibration, Road surface profiles, Reporting of measured data, 1995

[8]. ISO 2631-1 (1997), Mechanical vibration and shock-Evanluation of human exposure to whole-body vibration, Part I: General requirements, The International Organization for Standardization.

[9]. Zhou Changfeng, Dynamic modeling, optimization and experimental research of rubber suspension system of off-road vehicle, A dissertation submitted to Southeast University for the academic degree of doctor of engineering, 2007

[10]. Dodds C J, Robson J D, The description of road surface roughness, Journal of Sound and Vibration, 1973, Vol.31(2): 175–183.

[11]. Le Xuan Long, Le Van Quynh, et al(2021), Ride Performance Evaluation of Air and Hydro-Pneumatic Springs of Suspension System, International Journal of Advanced Research in Engineering and Technology (IJARET), Vol.12(1), pp.439-447

[12]. L Van Quynh, et al. Influence of semi-trailer truck operating conditions on road surface friendliness. Vibroengineering PROCEDIA, Vol. 16 (2017), pp. 67-72.

[13]. Le Xuan Long, Le Van Quynh, et al(2020), A Comparison of Ride Performance of Hydro-Pneumatic Suspension System with Those of Rubber and Leaf Suspension Systems, IOP Conf. Ser.: Mater. Sci. Eng. 914 012037