Research on the Safety of Intelligent Vibration Control System for Electric Vehicle Suspension

Mingjie Li*

Liaoning mechatronics college, Dandong 118009, China

*Corresponding author e-mail:limingjie@lnmec.net.cn

Abstract. Aiming at the problem of poor vertical vibration performance of electric vehicles, an integrated design scheme of electric vehicle suspension based on in-wheel vibration damping system is proposed, and the fuzziness between vehicle suspension and in-wheel vibration damping system is carried out for this scheme. control. Then, the LQR control method based on particle swarm optimization weight coefficient is adopted, and the LQR optimization controller is designed to comprehensively control the electric in-wheel vibration damping system and the vehicle suspension, and further optimize the vehicle ride comfort and electric wheel vibration performance. The simulation results show that the inversion control strategy based on the reference model can effectively suppress the vertical motion of the body, reduce the vertical acceleration of the body, and at the same time reduce the tire deformation to a certain extent, and improve the ride comfort and driving stability of the car.

Keywords: Active suspension; active vibration reduction; electric vehicle; vibration reduction control system.

1. Introduction

During the "Twelfth Five-Year Plan" period, Chinese electric vehicle technology has made great progress. The national "Thirteenth Five-Year Plan" outline points out that "the development of electric vehicle industrialization will be one of the priorities". The electric wheel drive system that installs the in-wheel motor inside the wheel has significant advantages in exerting the potential of dynamic control, simplifying the chassis structure, improving the driving efficiency, and enhancing the redundancy and reliability of the drive system. The electric wheel drive vehicle is a research vehicle. The ideal carrier of dynamic control potential and intelligence is considered to be one of the important development directions of the next generation of electric vehicles [1]. The curb weight of pure electric vehicles studied in China is generally around 1000kg. At the same time, in order to meet the power requirements of the whole vehicle, the mass of each in-wheel motor is as high as 30~52kg. If the in-wheel motor is directly rigidly connected to the wheel in the wheel, the unsprang mass will be significantly increased, resulting in a decrease in the mass ratio of the body to the wheel, and the performance of the three indicators of vehicle comfort will decrease near the wheel resonance peak, especially when the wheel is relatively the dynamic load varies greatly. When the absolute value of the relative dynamic load of the wheel is 1, if the dynamic load between the wheel and the ground and the static load acting on the ground by the wheel are equal in magnitude and opposite in direction, the vertical load acting on the ground by the wheel is equal to 0, and the wheel may jump off on the ground, the longitudinal and lateral adhesion is lost, and the driving safety of the vehicle is deteriorated [2]. Conversely, if the dynamic load between the wheels and the ground is equal to the static load acting on the ground and in the same direction, the damage to the road will be aggravated. In order to prevent the above situation from happening, it is necessary to reduce the relative dynamic load of the wheel while applying the in-wheel motor to drive the vehicle.

Aiming at the vertical negative effect of electric wheels on vehicles, this paper proposes a design scheme of electric wheel vibration reduction system, and uses particle swarm optimization (PSO) to match the initial parameters of the in-wheel vibration reduction system. a LQR algorithm based on particle swarm optimization weight coefficient is further adopted, and an LQR controller is designed to jointly control the in-wheel vibration damping force and the vehicle suspension damping force to improve the ride comfort of the vehicle and the vertical performance of the motor [3]. Finally, the effect is verified by MATLAB/Simulink simulation experiment.

2. Electric wheel scheme design and modelling

The electric wheel integration scheme is designed in the traditional electric wheel. Take the outer rotor hub motor as an example. The stator of the motor is fixed with the wheel shaft, and the rotor is fixed with the wheel hub. The hub motor is an inherent part of the unsprang mass, so the wheel is subjected to the road impact force directly acts on the in-wheel motor, which affects the working stability and reliability of the motor [4]. In order to reduce the vertical impact force on the in-wheel motor, this paper designs a controllable in-wheel vibration damping system for the electric wheel using the outer-rotor in-wheel motor.

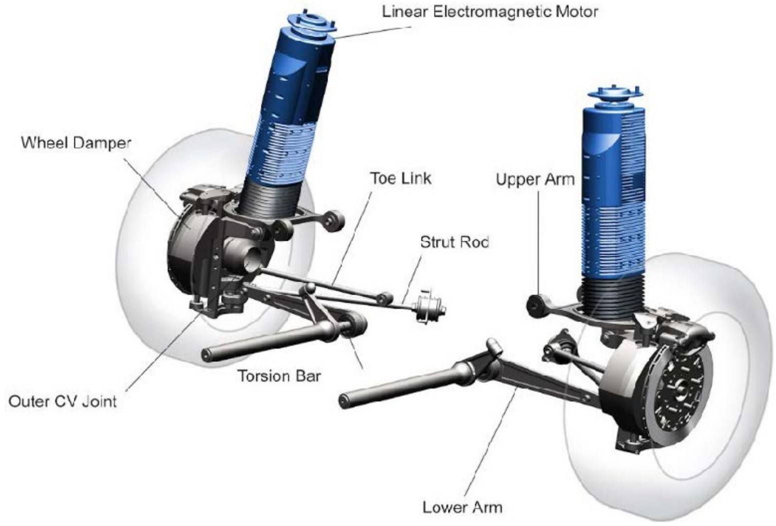

Figure 1. Electric wheel integration scheme based on in-wheel vibration reduction system

Figure 1 shows the scheme of the electric wheel based on the controllable vibration damping system in the wheel (the picture is quoted from Active suspension control of electric vehicle with in-wheel motors). One end of the motor rotor is connected to the wheel hub through positioning bolts, and the other end is the cover is fixedly connected with the brake disc, so as to realize the driving and braking of the wheel; one end of the motor stator is designed as an extension body with an outer square and an inner circle, which is used to install the in-wheel vibration damping system [5]. The in-wheel vibration damping system is composed of a damping spring and a hydraulic bushing. The damping spring connects the outer edge of the outer extension of the stator and the sprung mass of the vehicle; inside the outer extension of the stator, a hydraulic bushing is installed to cover the wheel axle. When the wheel vibrates under the excitation of the road surface, the in-wheel vibration damping system can play a role in damping vibration. If the hydraulic bushing is replaced by an annular bushing with fixed parameters (such as rubber bushing), the damping spring and bushing can play a passive vibration damping role; when the damping force of the hydraulic bushing is controllable, it can play a role in passive vibration reduction. to the role of active vibration reduction, thereby improving the adaptability of the vibration reduction system to complex working conditions.

The in-wheel vibration damping system shown in Figure 1 changes the connection between the motor stator and the wheel shaft from a rigid connection to a flexible connection, which realizes the mounting and Vibration isolation [6]. However, the system does not significantly change the structure and connection between the wheel, wheel axle and suspension.

2.1 Mathematical model

The active suspension model of a quarter car is shown in Figure 2 (the picture is quoted from Approximation-Free Control for Vehicle Active Suspensions with Hydraulic Actuator). The dynamic mathematical model of the suspension is briefly described as follows: the wheels and axles pass through springs, dampers the actuator and the actuator are connected to the car body, and the car tire is regarded as a simple spring [7]. In the figure, Mb is the unspring mass, Mw is the tire mass, Ca is the damping coefficient, Ka is the suspension spring stiffness, and Kt is the tire stiffness. In addition, the maximum value $\overline{z_1}$ of the suspension dynamic stroke is specified.

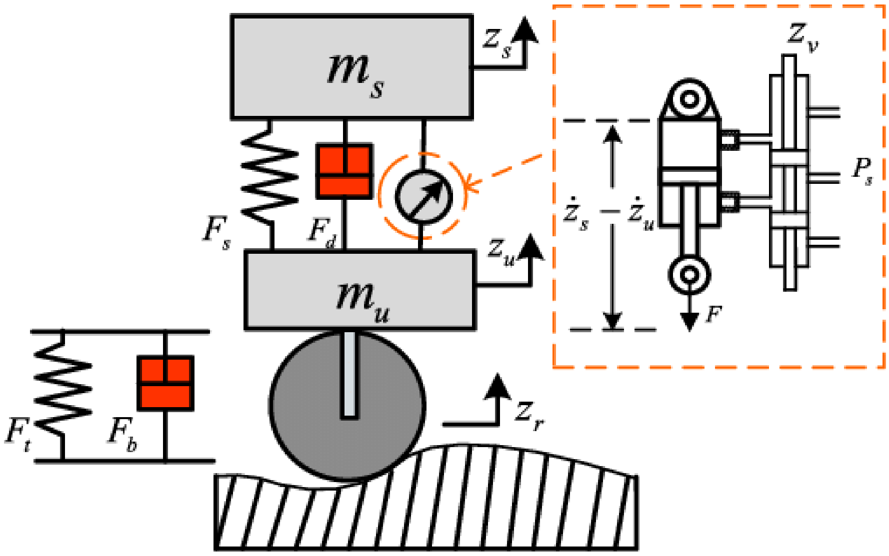

Figure 2. Quarter-car active suspension model using hydraulic actuators and springs/dampers

When the suspension travel is within its limits, the dynamic model of an automotive suspension system excluding actuators can be described by the following linear equation:

$$\begin{bmatrix} \dot{Z}_1 \\ \dot{Z}_2 \\ \dot{Z}_3 \\ \dot{Z}_4 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -\frac{K_a}{M} & -\frac{C_a}{M} & \frac{K_t}{M_w} & 0 \\ 0 & 0 & 0 & 1 \\ \frac{K_a}{M_w} & \frac{C_a}{M_w} & -\frac{K_t}{M_w} & 0 \end{bmatrix} \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \end{bmatrix} + \begin{bmatrix} 0 \\ -\frac{K_t}{M_w} \\ 0 \\ \frac{K_t}{M_w} \end{bmatrix} r + \begin{bmatrix} 0 \\ \frac{1}{M} \\ 0 \\ -\frac{1}{M_w} \end{bmatrix} F \tag{1}$$

The above formula can be written in the following form:

$$\dot{Z}_l = Az_l + B_1 r + B_2 F \tag{2}$$

In the formula: $z_1 = x_b - x_w$ is the suspension travel, $z_2 = \dot{z}_1$, $z_3 = x_w$, $z_4 = \dot{z}_3$, r is the road disturbance input, and F is the control generated by the actuator. The parameter values of the quarter-car active suspension model are: Mb=49kg, Mw=59kg, Ka=16812N/m, Ca=1000Ns/m, Kt=190000N/m.

2.2 Control strategy

Within the allowable service life of each component of the suspension system, the input excitation is based on the road surface to maximize the comfort of the passengers [8]. Comfort is measured by the amount of vertical acceleration of the body felt by the passenger. The control objectives to be achieved by the controller can be summarized as: (a) the suspension dynamic travel is within the limit value range, and the range of typical road disturbance input is increased; (b) the peak value of the vertical vibration acceleration of the vehicle body is minimized. Set the road disturbance input r(t) as:

$$r(t)=\begin{cases}a(1-\cos(8\pi))/2 & 0.5\le t\le 0.75\\ 0 & otherwise\end{cases} \tag{3}$$

3. Design method

To achieve the above control goals, we propose the following two design tasks: 1. Design an inner-loop controller to track the control force output by the actuator; 2. Design an outer-loop controller to control the actuator to produce satisfying control over performance requirements. The inner loop controller controls the input u of the actuator, and makes the actuator output the required control force according to the control signal Faced. And the inner loop controller further linearizes the output of the actuator [9]. The outer loop controller tracks the control signal Faced according to the magnitude of the input disturbance on the road surface to generate the force required for control to achieve the control target. To this end, we design a fuzzy controller to implement the control action according to the magnitude of the road input disturbance. The control system model diagram is shown in Figure 3 (the picture is quoted from Stability analysis and fuzzy smith compensation control for semi-active suspension systems with time delay).

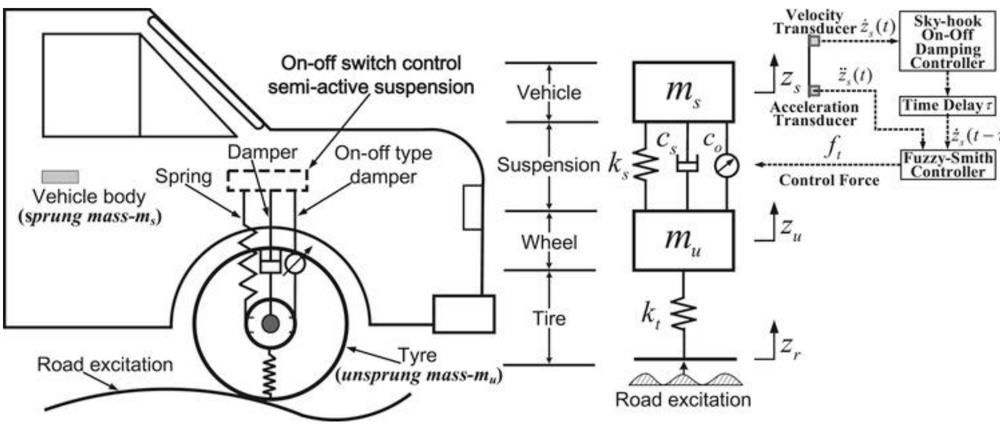

Figure 3. Control system model diagram

4. System Simulation Analysis

MATLAB/Simulink software is used to establish an optimally controlled in-wheel motor active vibration reduction system model. According to the GB/T4970-1996 random input driving test method for vehicle ride comfort, the simulation of C-level road driving in a straight line at a uniform speed is carried out [10]. The vehicle speed is 70km/h. Ordinary cars with 7 degrees of freedom without in-wheel motors (excluding in-wheel motor mass), electric wheel vehicles with 7 degrees of freedom rigidly installed in-wheel motors, and electric wheel vehicles with active vibration reduction of in-wheel motors proposed in this paper 11 degrees of freedom with active vibration reduction control comparison of electric-wheeled vehicles. It can be seen from Figure 4 that the electric wheel vehicle body acceleration, pitch angle acceleration and roll angle acceleration power spectral density amplitude caused by the rigid connection of the wheel hub motor is mainly concentrated in the frequency range of 5~12Hz. The in-wheel motor active vibration reduction system (electric wheel vehicle with active vibration reduction control) can achieve the same effect as ordinary cars in the vertical acceleration, pitch angular velocity and roll angular acceleration power spectral density before 12Hz. Obviously, the problem of vehicle vertical negative effect in the 5~12Hz frequency domain is solved (the picture is quoted from Semi-Active Vibration Control for in-Wheel Switched Reluctance Motor Driven Electric Vehicle with Dynamic Vibration Absorbing Structures: Concept and Validation). In the frequency range greater than 12Hz, the amplitudes of electric wheel vehicles with active vibration reduction control and electric wheel vehicles are both smaller than those of ordinary vehicles, so electric wheel vehicles have no changes in ride comfort and body attitude angle of the original vehicle in the frequency range greater than 12Hz. It can be seen that the electric wheel vehicle with active vibration damping control can not only eliminate the influence of the fixed installation of the in-wheel motor on the ride comfort of the original car, but also improve the ride comfort of the original car.

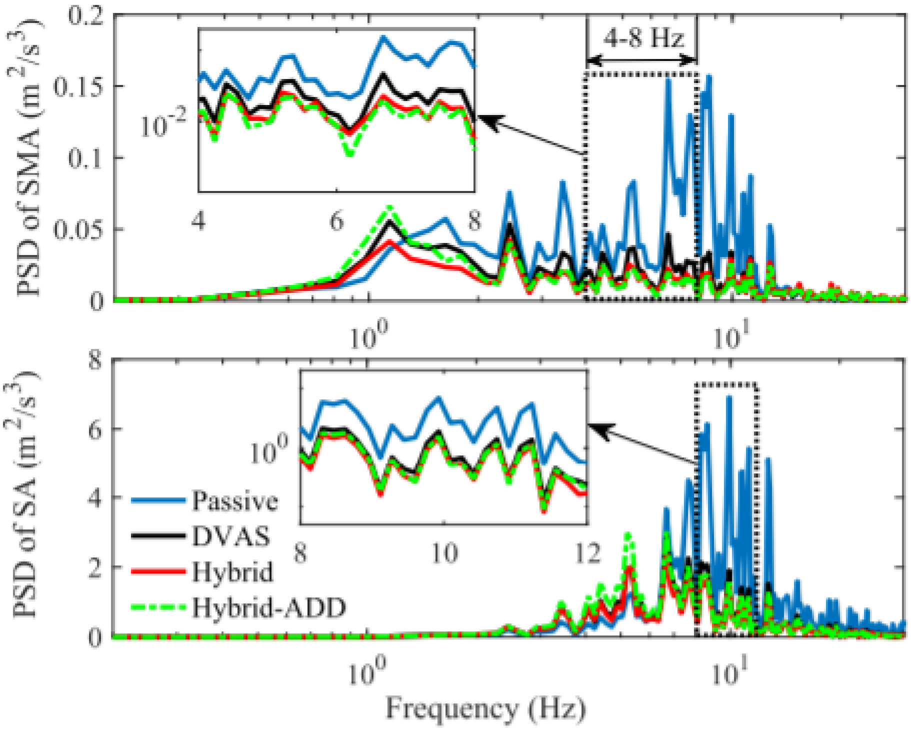

Figure 4. The relative wheel travel of the in-wheel motor connected to the active vibration damping system

5. Conclusion

An integrated design scheme of the electric wheel structure based on the in-wheel vibration reduction system is proposed, and the main control force and the in-wheel control force are optimized simultaneously based on the particle swarm LQR control algorithm. The dynamic deflection and motor impact force are used as the evaluation indicators of the electric wheel vibration reduction system, which verifies the reliability and effectiveness of the proposed electric wheel structure and its control algorithm. Compared with the traditional electric wheel system, the electric wheel based on the in-wheel vibration damping system has obvious advantages in terms of body acceleration, relative dynamic load of the wheel and the impact force of the motor. And there is a certain relationship between the relative dynamic load of the wheel and the impact force of the motor. If one performance is optimized, the other performance index will be improved accordingly.

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References

[1] Feng Fan. Modelling and Simulation Analysis of Automobile Damping System Based on Finite Element Method. Electronic Design Engineering, 29(6) (2021) 41-47.

[2] Mu Zengguo, Zhang Jiping, Li Hongming. The effect of prestress on the natural frequency of automobile shock absorbers. Machinery Manufacturing and Automation, 50(1) (2021) 14-19.

[3] Xie Yawen. Semi-active suspension system based on damping multi-stage segment adjustment. Computer Measurement and Control, 28(2) (2020) 55-62.

[4] Zhang Xiaojuan. Research on Control Strategy of Automobile Semi-active Suspension——Comment on "New Technology of Automobile Suspension System". Mechanical Design, 8(9) (2020) 14-19.

[5] Wei Ya, Kang Fan. Application form and progress of carbon fiber composite materials in new energy vehicles. Bonding, 42(4) (2020) 55-61.

[6] Nie Xiaoyong, Yang Hai, Li Shenguo, et al. Application of Vacuum Die Casting Aluminum Alloy Shock Tower on Aluminum Body. Special Casting and Nonferrous Alloys, 40(3) (2020) 57-68.

[7] Wu Wenwang, Xiao Dengbao, Meng Jiaxu, et al. Mechanical design of structures with negative Poisson's ratio, impact resistance and its application and prospect in vehicle engineering. Chinese Journal of Mechanics, 53(3) (2021) 28-33.

[8] Gong Xiaofeng, Yu Renping, Xing Qin. Design of complex multi-station continuous die for automotive interior reinforcements. Forging Technology, 45(12) (2020) 65-72.

[9] None. AIWAYS' U5 with steel-aluminum hybrid body was launched in December 2019. Special Casting and Nonferrous Alloys, 40(1) (2020) 11-17.

[10] He Yuyang. Application of Phononic Crystal Structure Panels in Noise Control in Vehicles. Noise and Vibration Control, 40(6) (2020) 55-60.