Optimization of Vehicle Suspension Parameters Based on Genetic Algorithm

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Abstract: Vehicle handling stability and ride comfort are two important properties in the car’s performance. The main purpose of this paper is to improve the ride comfort of the vehicle on the basis of both handling and stability, so as to improve the ride comfort of the vehicle under the condition of ensuring the handling and stability. In this paper, a parameter model of vehicle suspension is established, and the dynamic equation used to solve the parameter model is given. In order to improve vehicle ride comfort under the premise of guaranteeing handling stability, genetic algorithm is used to optimize vehicle body vertical acceleration, dynamic deflection of suspension spring and relative dynamic load, taking body mass, wheel mass, suspension spring stiffness, tire stiffness and shock absorber damping as design variables, the vehicle structural parameters are optimized, and the optimization results are obtained through the genetic algorithm toolbox of MATLAB. Finally, the optimization parameters are simulated and the curves of vertical acceleration, relative dynamic load and suspension dynamic deflection with time are obtained. Compared with the simulation results before optimization, the optimized vertical acceleration, relative dynamic load and suspension dynamic deflection are obviously reduced, and the effect is better.

Keywords: Vehicle suspension; ride comfort; genetic algorithm; multi-objective optimization

1 Introduction

The shock absorber in vehicle suspension is usually referred to as hydraulic shock absorber, which is the most precise and complex mechanical part in vehicle suspension structure. The vehicle absorbs the vibration through the shock absorber in the suspension structure to ensure that the vibration of the vehicle body weakens rapidly, so that the body can reach a stable state quickly. The research of vehicle suspension shock absorption control system is of great significance to practical engineering application [1–3].

Because of the uneven road, the vibration of the car is inevitable in the course of driving, which affects the comfort of passengers. The main reason affecting vehicle vibration is unreasonable design, and improper suspension design is one of the important reasons affecting ride comfort. At present, there are many methods to study vehicle comfort, such as linear motor energy-fed suspension in reference [4–6]. Under the excitation of road surface irregularity, the calculation methods of ride comfort and feedback energy power flow are deeply studied. In reference [7–9], road surface spectrum is adopted to generate random road surface irregularity, and a mathematical model of vehicle vibration is established, which generates irregularity by inputting random road surface. In reference [10–12], the bridge vibration equation is established by finite element method, and the calculation program is compiled by ANSYS software. The parameters of bridge dynamic response, vehicle self-weight and suspension stiffness are calculated, and the influence of vehicle driving on ride comfort is evaluated.

At present, there are few literatures about the optimization of vehicle suspension parameter model. Therefore, this paper uses genetic algorithm and MATLAB simulation platform to optimize the vehicle suspension parameter model. First of all, by establishing the vibration parameter model of vehicle suspension, the dynamic equation for solving the parameter model is given. Then genetic algorithm is used to optimize the parameters of vehicle suspension, and the optimized parameters are obtained. Then the optimized parameters are input into the MATLAB module for simulation, and the
vibration response curve with time is obtained. Finally, by comparing with the simulation results before optimization, the corresponding conclusions is given.

2 Establishment of model

The establishment of vehicle suspension system model is the basis of the research work in this paper. It is very important to establish a practical experimental model. Therefore, it is required that the established system model can be consistent with the basic dynamic performance of the actual system, and it is also convenient for theoretical analysis and research. The actual vehicle suspension system is a complex vibration system. In the process of random vibration of vehicles, the two-degree-of-freedom vibration model is usually used. As shown in Figure 1, that is, the two-degree-of-freedom quarter vehicle model. The model is given as below:

\[
\begin{align*}
\dot{x}_1 + c_1 (\dot{x}_1 - \dot{x}_2) + k_1 (x_1 - x_2) &= 0 \\
\dot{x}_2 - c_1 (\dot{x}_1 - \dot{x}_2) - k_1 (x_1 - x_2) + k_2 (x_2 - x_0) &= 0
\end{align*}
\]

where the body mass and wheel mass are expressed by \(m_1\) and \(m_2\) respectively (\(m_1\) and \(m_2\) can only do vertical translation), and their vertical displacements are \(x_1\) and \(x_2\), spring stiffness \(k_1\) and linear damping \(c_1\), respectively. If the tire stiffness is \(k_2\), the road excitation is expressed by \(h(t)\). \(x(t)\) is a white noise process with covariance when a car is traveling at a constant speed \(v\).

Figure 1: Quarter Vehicle Dynamics Model

The two-degree-of-freedom vibration system of car body and wheel has first-order main mode and second-order main mode. In the case of strong Chasing vibration, low-frequency resonance vibrates according to the first-order main mode, mainly spring-loaded mass; high-frequency resonance vibrates according to the second-order main mode, mainly non-spring-loaded mass.

For the parameter optimization problem in this paper, the following assumptions need to be made:

1. Both mount mass and non-mount mass are rigid bodies. The tire model simulates vehicle-to-ground contact and is simplified to a spring with equivalent stiffness.
2. When the vehicle runs at a uniform speed on the road, the tires keep in contact with the ground, and the geometric displacement of the static equilibrium state of the vehicle is linear small displacement.
3. The elastic and damping characteristics of springs, shock absorbers and tires can be described by linear functions of displacement and velocity.
4. The displacement function of road excitation is applied to wheels by point contact: external excitation, external force (including inertia force produced by aerodynamics, steering and braking) with road disturbance.

3 Parameter optimization design process

There are three important indexes to evaluate vehicle ride comfort: vertical acceleration of vehicle body, relative dynamic load and suspension dynamic deflection. Vehicle body vertical acceleration \(\ddot{x}_1\) is an important parameter reflecting...
occupant comfort in the three evaluation indexes. The larger the value, the more uncomfortable the occupant is. On the contrary, the smaller the value, the more comfortable the occupant is. Therefore, in the mathematical model, the objective function takes the minimum value of $\ddot{x}_1$, that is, the objective function is:

$$f = \int_0^T (\ddot{x}_1)^2 \, dt$$

(2)

where $T$ takes 50s.

According to reference [13], we give the following parameter optimization:

$$\text{min } f = \int_0^T (\ddot{x}_1)^2 \, dt$$

s.t. $288000 \leq m_1 \leq 352000$

$36000 \leq m_2 \leq 44000$

$16200 \leq k_1 \leq 19800$

$180000 \leq k_2 \leq 220000$

$900 \leq c_1 \leq 1100$

For the convenience of design optimization, let $\frac{dx_1}{dt} = x_3$, $\frac{dx_2}{dt} = x_4$, then the model can be transformed into the following differential equation:

$$\begin{cases}
\frac{dx_1}{dt} = x_3 \\
\frac{dx_2}{dt} = x_4 \\
\frac{dx_3}{dt} = \frac{c_1}{m_1} (\ddot{x}_1 - \dddot{x}_1) + \frac{k_1}{m_1} (x_2 - x_1) \\
\frac{dx_4}{dt} = \frac{c_1}{m_2} (\ddot{x}_1 - \dddot{x}_1) + \frac{k_1}{m_2} (x_1 - x_2) + \frac{k_2}{m_2} (x_0 - x_2)
\end{cases}$$

4 Simulation

For the rewritten model, genetic algorithm is used to optimize the parameters. The number of individuals:100, generations: 250. The optimization result is shown in Figure 2:

![Figure 2: Optimization results of genetic algorithm](http://www.nonlinearscience.org.uk/)

Therefore, through the MATLAB and genetic algorithm toolbox, the optimization results obtained in this paper are as follows:

$$m_1 = 351953.464 g, m_2 = 36001 g, k_1 = 16200 N/m$$

$$k_2 = 180202.361 N/m, c_1 = 1098.324 Ns/m$$

Table 1 shows the comparison of design variables before and after optimization.

| Table 1. Comparison of design variables before and after optimization |
|-------------------------|-------------------------|

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The following is the comparison of vibration response before and after optimization.

(1) Body acceleration

![Figure 3: Curves of body acceleration versus time before and after optimization](image)

(2) Relative dynamic load

![Figure 4: Time-dependent curve of relative dynamic load before and after optimization](image)

(3) Dynamic deflection of suspension

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Figure 5: Dynamic deflection curve of suspension before and after optimization with time

It can be seen that the vertical acceleration after optimization is reduced to a certain extent compared with that before optimization; for the tire dynamic load, the optimized tire dynamic load is smaller than that before optimization, and it is basically impossible for the tire to jump off the ground; for the suspension dynamic deflection is also reduced, so the probability of the suspension hitting the limit block will also be reduced. In summary, the ride comfort of the vehicle has been improved by optimizing the suspension characteristic parameters.

5 Conclusion

Based on a two-degree-of-freedom quarter vehicle model, in order to improve vehicle ride comfort on the premise of guaranteeing handling sustainability, the suspension system is optimized. The vehicle body mass, wheel mass, suspension spring stiffness, tire stiffness, tire stiffness and shock absorber damping are optimized with the objective of vertical acceleration, dynamic deflection of suspension spring and relative dynamic load. By comparing the optimization results obtained by the genetic algorithm toolbox of MATLAB with the simulation results before optimization, the results show that the vertical acceleration, relative dynamic load and dynamic deflection of the optimized vehicle body are significantly lower than those before optimization, and the effect is better. From the above comprehensive analysis, it can be seen that the ride comfort of the vehicle has indeed been improved by optimizing the suspension sustainability parameters.

References


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