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Design of Suspension Parameter Optimization System for Heavy Highway Semi Trailer Transport Vehicle

Qinglai Chen[1,*]
Mechatronics System, Huaibei Vocational &Technical College, Huaibei, Anhui, China, 235005

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Abstract

Heavy highway semi-trailer transport vehicle is a kind of vehicle with high loading quality, which has the advantages of low fuel consumption and high transportation efficiency. At the same time, the semi-trailer transport vehicle has the advantages of drop and pull transport, which has occupied a growing proportion of heavy goods vehicles in the transportation industry. However, due to the high position of mass center, long body and small wheelbase, semi-trailer transport vehicles are prone to lateral instability such as sideslip, tail flick and folding, which will cause casualties and property losses. Therefore, we need more in-depth study of the semi-trailer vehicle mounting system, which will better improve the ride comfort of the vehicle. By studying the mounting system, we can optimize the mounting parameters, which will improve the performance of the vehicle. Firstly, this paper analyzes the classification of vehicle mounting system. Then, this paper analyzes the vehicle vibration theory. Finally, this paper optimizes the parameters based on an example.

Keywords: *Heavy highway, Semitrailer, Mounting system, Parameter optimization;*

1. Introduction

Mitsubishi Corporation of Japan has studied the mounting characteristics of semitrailer. According to the natural frequency configuration requirements of each vibration subsystem, Mitsubishi company divides the mounting system into the following aspects[1].First, the main suspension. Generally speaking, the resonance frequency of the sprung mass of the semitrailer is higher than that of the car. When the resonance frequency of the sprung mass is equal to or lower than that of the car, it is most advantageous to improve the ride comfort by reducing the stiffness of the main suspension spring[2]. Second, the cab suspension. Different types of suspension will be adopted according to the specific frequency of the suspension[3]. Third, seat suspension. For semi-trailer transport vehicles, most of the seat mounts are equipped with stroke adjustment mechanism, which has a large degree of design freedom. When the resonance frequency of the seat mount is set lower than that of the main suspension and cab mount, the seat has obvious damping effect. Therefore, it is better to reduce the stiffness of the seat mounting[4]. Fourth, seat cushion. The seat cushion has nonlinear stiffness characteristics, which can absorb high frequency vibration. Fifth, vehicle structure mounting[5].Due to the different types of vehicles, different axle arrangement, wheelbase and road conditions will lead to different cab vibration levels. Sixth, engine mount. Good engine mounting system can reduce the transmission of engine vibration to the vehicle body, which will reduce the interior noise and improve the vehicle comfort. Therefore, the engine mounting system can control the vehicle vibration and noise, which is an important part of the vehicle independent development and design. The vibration isolation effect of cab mounting system not only depends on the selection of structural form, geometric position, stiffness and damping of elastic elements, but also has an important relationship with the performance parameters of chassis suspension system. In the imitation design of domestic enterprises, the performance parameters of the mounting vibration isolation system are often selected improperly, resulting in poor vibration isolation effect[6].The engine mount with good performance can effectively control the transmission of excitation force to chassis when the engine is working, which will reduce the vibration of engine and vehicle. By reducing the force transmitted by the engine mounting system to the body, we can stimulate the vibration and noise of the metal parts of the body and chassis related parts, which will improve the durability and riding comfort of the car[7].

In the 1930s, people began to study the vibration characteristics of the whole vehicle, including the natural frequency of components and the reasonable matching of suspension stiffness. With the deepening of the research, the traditional two degree of freedom method restricts the research of vehicle ride comfort. With the continuous development of social economy, people have higher and higher requirements for vehicle ride comfort. In order to improve the competitiveness, automobile enterprises pay more and more attention to the research of vehicle ride comfort, which is gradually extended to many theories such as random vibration, modal analysis and so on. Through the finite element analysis software, we can build a 954 degree of freedom vehicle model, which will truly simulate the real vehicle structure. Through the simulation study, the model of semitrailer can well predict the ride comfort performance[8].

At present, there are two kinds of optimization methods for suspension system, which are modal solution method and dynamic response method. The modal solution method is carried out by adjusting the stiffness matrix of the powertrain mounting system. We can change the mode of the system, which will control the response of the system to excitation. By optimizing the parameters of the mount, we can reduce the force transfer between the powertrain and the body, which is the basic principle of the dynamic response method[9].

2. Structure of semi hung transport vehicle

2.1. The structure characteristics of semi-trailer

Trailer is a vehicle without its own power device, which requires the help of vehicle traction to drive normally. According to whether it is fully loaded, the trailer can be divided into full trailer and semi trailer. The total mass of the trailer is entirely borne by itself, and the rear end of the tractor is equipped with a tow hook, which can be connected with the traction ring at the front of the trailer [10]. The tractor only provides power, which does not take the load of the full trailer. The total mass of semi-trailer is not entirely borne by the semi-trailer, and the traction device can transfer horizontal force and vertical force to the tractor. The mass of the tractor attachment of the semi-trailer is mostly from the load mass. Therefore, semi-trailer does not need weight, its transportation power utilization rate is high, and economy is better[11].

The common structure of traditional semi-trailer is shown in Figure 1, which is mainly composed of gooseneck, cargo box, leg and frame. The gooseneck is equipped with a traction pin, which is connected with the traction seat of the tractor, which can transfer the power and relative motion between the tractor and the semi-trailer. The frame is the main cargo loading device.

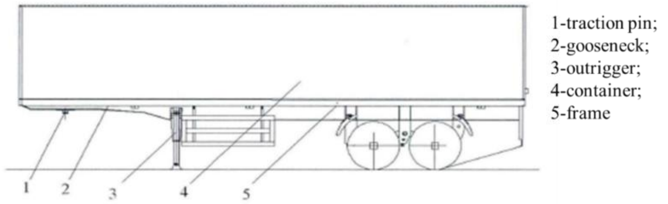

Figure 1. Structure diagram of traditional semi-trailer.

2.2. The main factors affecting the ride comfort of semitrailer

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The main factors that affect the ride comfort of semi-trailer include suspension structure, loading form of goods and matching of suspension parameters. In order to improve the ride comfort, the traditional semi-trailer will use leaf spring to balance the suspension. In the vehicle driving, the balanced suspension can avoid the wheel suspension phenomenon, which helps to improve the vehicle handling stability and vehicle ride comfort[12]. The loading form of goods not only affects the ride comfort of the vehicle, but also affects the structural design of the frame. We can improve the smoothness of the goods in the process of transportation by special shock absorption packaging. According to the different goods loaded, the structure of the frame is often different, such as the location of the fixing hole, the position of the oil way of the frame, etc., which requires our specific transportation requirements to be changed. There are two basic structural forms for the frame of semi-trailer transport vehicle, namely flat plate structure and Yuanbao structure, as shown in Figure 2. Compared with the flat panel frame structure, Yuanbao type frame structure design is more complex, which can reduce the height of cargo centroid[13]. In the process of transportation, we can improve the transportation smoothness and handling stability of the semi-trailer.

According to the structural characteristics of the semitrailer and the analysis of the influencing factors, we have many ways to improve the ride comfort of the semitrailer. First, we can improve the way of loading goods. We can use shelves with suspended structure. Second, we can use advanced suspension structure or match the suspension parameters to design the suspension suspension system[14].

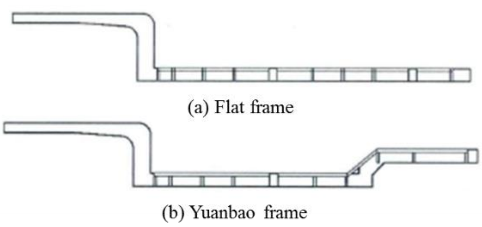

Figure 2. Different frame structures.

3. Theoretical basis of automobile vibration

3.1. Vibration foundation

The vehicle body and many systems are continuous systems. In practical analysis, we can transform continuous system by discretization, which is called multi degree of freedom system.

The dynamic equation of a multi degree of freedom system can be written in the form of matrix, as shown in Formula 1.

$$M\ddot{x}+C\dot{x}+Kx=F(t) \qquad (1)$$

Among them, M, C *and* K are mass matrix, damping matrix and stiffness matrix respectively, F is force vector.

The damping matrix is assumed to be the following combination, and the solution vector x is a linear combination of natural modes, as shown in formula 2.

$$\begin{aligned} C &= \alpha M + \beta K \\ x &= Xq(t) \end{aligned} \qquad (2)$$

Among them, α *and* β are constants. The solution vector x is expressed as a linear combination of natural modes. Therefore, we can get formula 3.

$$MX\ddot{q}(t)+(\alpha M+\beta K)X\dot{q}(t)+KXq(t)=F(t) \qquad (3)$$

In this paper, we regularize the eigenvector, and we can get formula 4.

$$IX\ddot{q}(t)+(\alpha I+\beta\omega^2)\dot{q}(t)+\omega^2 q(t)=Q(t) \qquad (4)$$

Among them, $Q(t)=X^T F(t)$

If the external force $F(t)$ is a periodic force with a period of $\tau = 2\pi/\omega$, its Fourier series is shown in the formula 5.

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$$F(t)=\frac{a_0}{2}+\sum_{j=1}^{\infty}a_j\cos j\omega t+\sum_{j=1}^{\infty}b_j\sin j\omega t$$
$$a_j=\frac{2}{\tau}\int_0^{\tau}F(t)\cos j\omega t dt,\ j=0,1,2,...,$$
$$b_j=\frac{2}{\tau}\int_0^{\tau}F(t)\sin j\omega t dt,\ j=1,2,...,$$
(5)

Therefore, we can get the equation of motion of the system as shown in formula 6.

$$M\ddot{x}+C\dot{x}+Kx=\frac{a_0}{2}+\sum_{j=1}^{\infty}a_j\cos j\omega t+\sum_{j=1}^{\infty}b_j\sin j\omega t$$
(6)

The steady-state solution of the equation is shown in formula 7.

$$x_p(t)=\frac{a_0}{2k}+\sum_{j=1}^{\infty}\frac{a_j/k}{\sqrt{(1-j^2r^2)^2+(2\zeta jr)^2}}\cos(j\omega t-\phi_j)+\sum_{j=1}^{\infty}\frac{b_j/k}{\sqrt{(1-j^2r^2)^2+(2\zeta jr)^2}}\sin(jwt-\phi_j)\quad(7)$$
$$\phi_j=\arctan\frac{2\zeta jr}{1-j^2r^2};\quad r=\frac{\omega}{\omega_n};\quad \omega_n=\sqrt{\frac{k}{m}};\quad \zeta=\frac{c}{c_c}=\frac{c}{2\sqrt{mk}}$$

3.2. Composition of vibration control system

There are several ways to eliminate vibration. First, vibration elimination. By reducing the vibration of the vibration source, we can eliminate the vibration, which is the fundamental method. Second, vibration isolation. Between the vibration source and the object, we can install vibration isolation elements, which will respond to the vibration source excitation by reducing the object. Third, vibration absorption. In the control object, we can attach a subsystem, which can reduce the response of the control object, such as the harmonic oscillator on the engine. Fourth, damping vibration, namely damping vibration reduction. By damping, we can consume energy, which will reduce the vibration response.

4. Mounting system of semitrailer

4.1. Mounting system composition

The mounting elements of the powertrain are used as limit and support functions. It is hoped that the stiffer the mounting, the better, which will avoid interference of parts. As a vibration isolation function, the smaller the mounting element stiffness, the better. Therefore, these two aspects are a contradiction, which is a very important key issue. In the design of the mounting system, we need to select the stiffness of the mounting element by means of optimization. The ideal powertrain mount will be responsible for preventing the engine bounce caused by ground shock excitation. The stiffness, position and damping of powertrain mount will become the main object of vibration reduction, which is the development of powertrain mount system.

4.2. Simplified model of mounting element

For the rubber mounting element, if the force acting on the rubber element only has elastic displacement in the force direction, which will not cause displacement in other directions, we can call the force acting direction as the elastic principal axis direction of the rubber element. The three-dimensional elastic principal axes along the direction of the elastic principal axis intersect at a point, which can be called the elastic center. The stiffness along the elastic spindle direction is called the spindle stiffness. Therefore, if the force passes through the elastic center of the rubber element along the main axis direction, the rubber element will only shift but not angular displacement. The shape of the mounting element itself is related to the elastic center position and elastic principal axis direction of the rubber mounting element. The dynamic model of mounting element is shown in Figure 3.

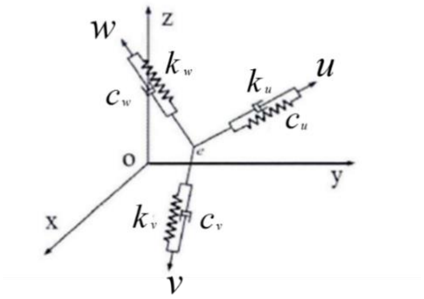

Figure 3. The dynamic model of mounting element.

The dynamic mathematical model of mounting element is shown in formula 8.

$$[C]\left\{\dot{X}\right\}+[K]\{X\}=\{F\} \tag{8}$$

4.3. Arrangement of mounting system

4.3.1. Three point support

Three point support is shown in Figure 4. Three point mounting is commonly used in small and medium-sized passenger cars. It has the advantages of simple system, small number of parts, low cost, less space occupation and less possibility of over positioning. At the same time, the natural frequency of the three-point mount is low, which can well resist torsional vibration. Common form: the first two points are inclined to the left and right, and the rear end is arranged according to the main inertia axis. This method is commonly used in the longitudinal four cylinder engine.

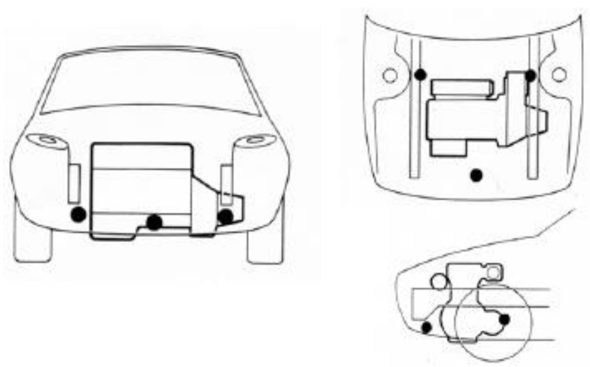

Figure 4. Three point support.

4.3.2. Four point support

Four point support is shown in Figure 5. Compared with three-point mounting, four-point mounting has better system stability, less load on single mounting part, and can bear larger powertrain torque; however, it also has high torsional stiffness and poor low-frequency vibration isolation effect. At the same time, the mounting system is easy to produce over constraint, which makes the machining precision of parts high.

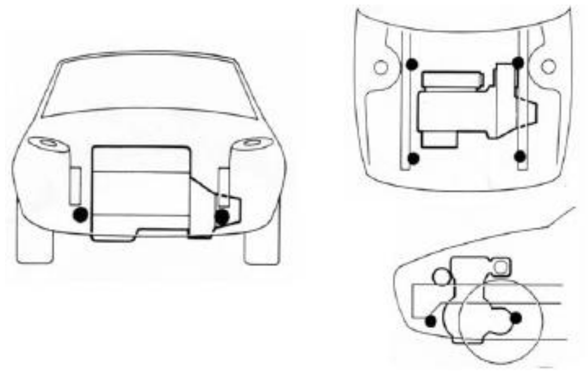

Figure 5. Four point support.

4.3.3. Five point support

Five point support means adding auxiliary support to the transmission, which will change the typical four point support into five point support. Construction vehicles, such as dump trucks and mixer trucks, are generally mounted at five points, which will improve the reliability in harsh environments.

4.4. Simplification of vehicle dynamics model

According to the structural characteristics of the semi-trailer, we use half of the whole vehicle after the traction mounting mechanism as the model, as shown in Figure 6. When modeling, we should consider the suspension system of traction, the mounting system of tractor and semi-trailer frame, which can ignore the engine and cab mounting system. The 1/2 vibration model of the whole vehicle is shown in Figure 6. The stiffness of the front suspension is KF and the damping is CF. The stiffness and damping of front suspension wheel, middle and rear axle leaf spring balance suspension,

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intermediate shaft and rear axle tire are shown in Figure 6.

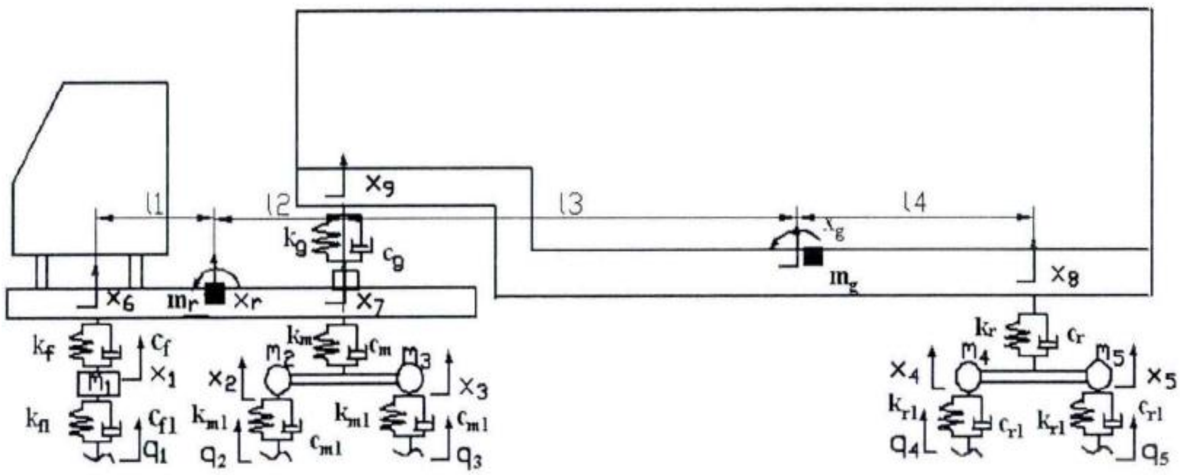

Figure 6. 1/2 vibration model of vehicle.

5. Optimal design of mounting system

5.1. Suspension system design process

The design process of mounting system is the core content of mounting design. The general process of mounting system design is formulated in this paper, as shown in Figure 7.

5.2. Optimization design of mounting parameters

By establishing a response surface model with high reliability, we can respond and optimize the design parameters. Before optimization, we can manually adjust the design parameter value, which will get the corresponding variable momentum of the evaluation target. In this way, we can determine the approximate range of design parameters, which can set the design parameters to a better initial value. In this way, we can find the final global optimal solution. In this paper, the suspension parameters are adjusted by changing the partial damping and stiffness. Through ADAMS/insight software, we can get the comparison of parameters before and after optimization, as shown in Table 1.

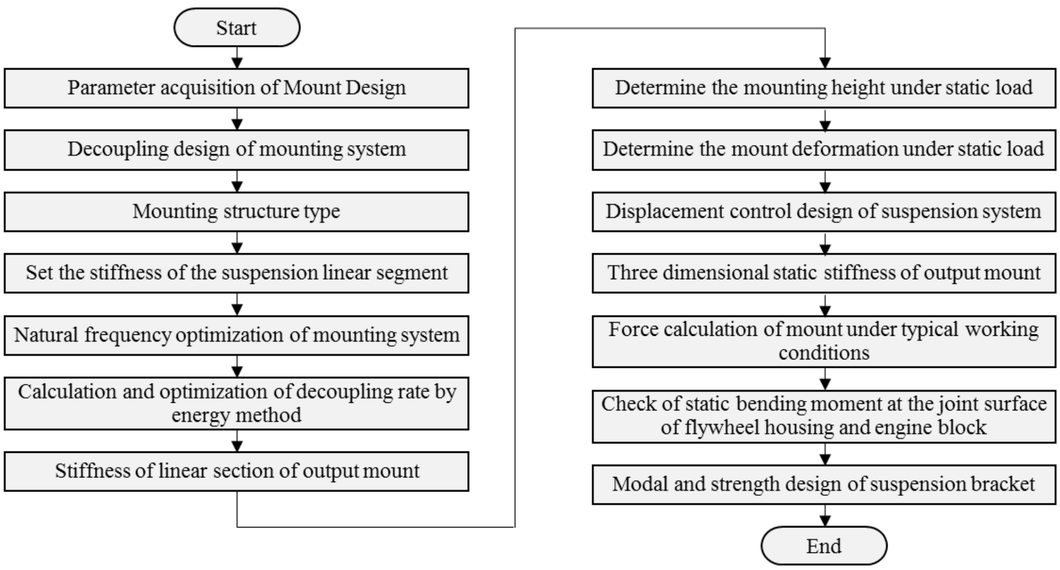

Figure 7. Suspension system design process.

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Table 1. The comparison of parameters before and after optimization.

Design variable	Before	After	Variation
Front suspension damping of main suspension	10	15.8	58.0%
Rear suspension damping of main suspension	10	17.96	79.6%
Front suspension stiffness of cab mount	45	28.85	-35.9%
Cab mount front suspension damping	6	4.48	-25.3%
Rear suspension stiffness of cab mount	80	44	-45.0%
Cab mount rear suspension damping	6	7.83	30.5%

5.3. Ride comfort verification

After the optimization of the design parameters into the model for simulation analysis, we can get the data of each evaluation target. Among them, the comparison diagram of output PSD curve in Z direction is shown in Figure 8, that in Y direction is shown in Figure 9, and that in X direction is shown in Figure 10.

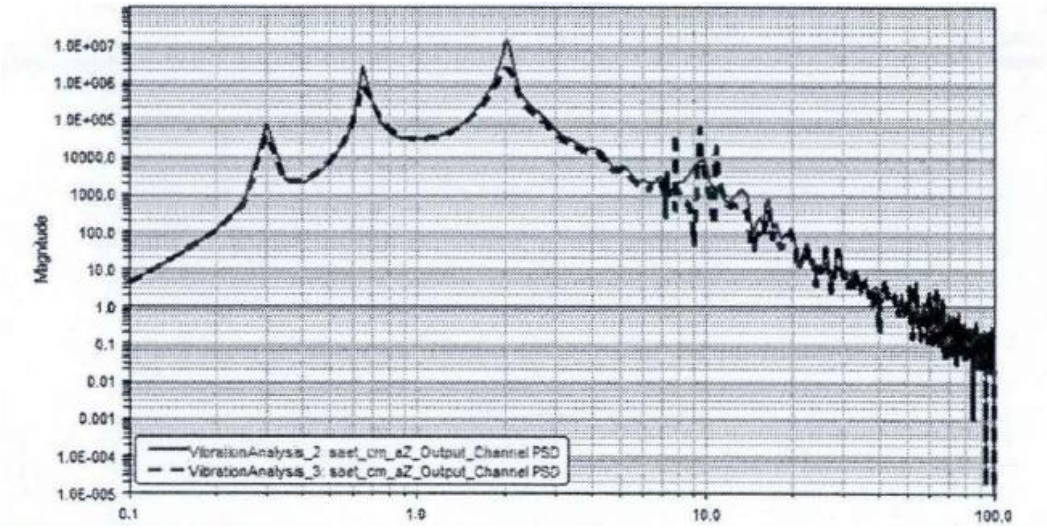

Figure 8. Comparison of PSD curves of Z-direction output.

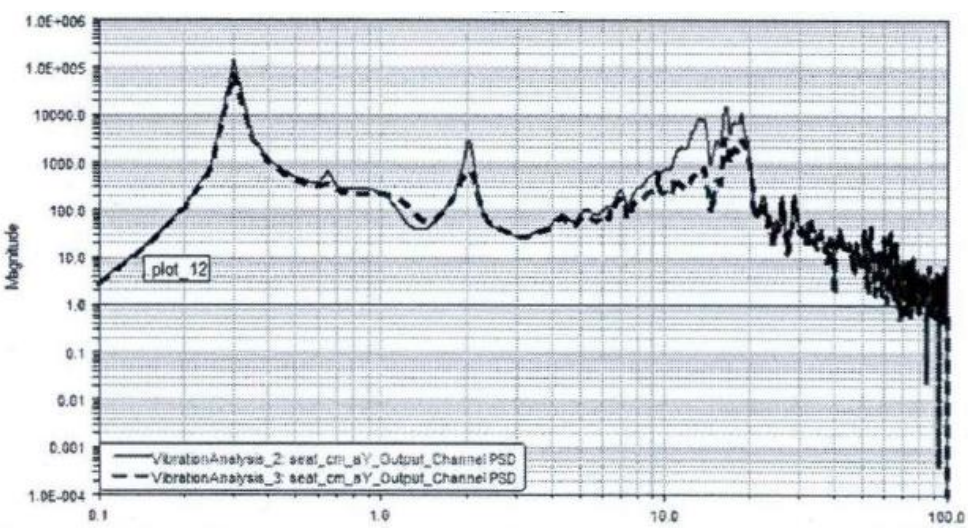

Figure 9. Comparison of PSD curves of Y-direction output.

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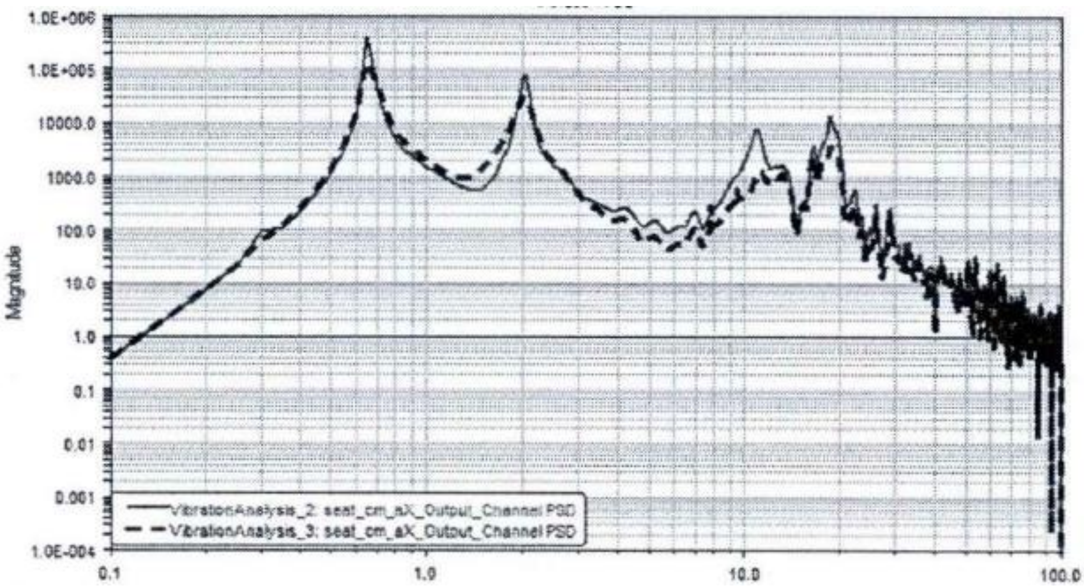

Figure 10. Comparison of PSD curves of X-direction output.

It can be seen from the figure that the target values of each evaluation are reduced to varying degrees. By integrating the curves, we can get the root mean square value of acceleration in each direction as shown in Table 2.

Table 2. Comparison of evaluation target values before and after optimization (m/s^2).

Evaluation objectives	Before	After	Variation
Root mean square value of acceleration in Z direction	10	15.8	58.0%
Root mean square value of acceleration in Y direction	10	17.96	79.6%
Root mean square value of acceleration in X direction	45	28.85	-35.9%

6. Conclusion

Through comparison, we get that the target value of each evaluation has different degrees of reduction. It can be seen that through the test design method, this paper establishes the response surface model for vehicle ride comfort analysis. Through response surface model optimization, we get the final parameters, the results show that the vehicle ride comfort is greatly improved.

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