Research on Vibration of Mechanical System Based on MATLAB

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Abstract—Mechanical vibration is the main factor affecting mechanical performance. This vibration will seriously affect the smoothness of the mechanical system and reduce the service life of mechanical system components. In addition, severe mechanical vibration may also affect the stability of the mechanical system and produce noise. Therefore, studying mechanical vibration and proposing control methods will be a significant task. This paper is mainly based on MATLAB to study the vibration of a typical mechanical system, namely the body and wheel dual-mass system, and obtain its amplitude-frequency characteristics, and focus on the influence of system parameters on the root mean square value of vibration. This research can provide a certain useful reference for reducing vehicle vibration and improving vehicle driving comfort.

1. INTRODUCTION
Mechanical vibration is the back and forth movement of an object near a certain position. This kind of vibration phenomenon is common in nature, engineering technology, and daily life. For example, the screaming of summer cicadas, the tiny vibrations of various parts when the machine is turned on, the swing of the pendulum, the beating of the heart, and other phenomena have obvious vibration characteristics. Although the vibration phenomena in different fields have their own characteristics, they have common objective laws. In order to explore the mechanism of various vibration phenomena and clarify the basic laws of vibration, it is necessary to apply mechanics knowledge to establish a mathematical model, usually a differential equation (set), and then analyze and solve the built model. This process involves tedious mathematical derivation and solving complex differential equations is tedious, time-consuming, and error-prone to solve manually. If you use computer software to solve it, you need a certain amount of computer programming knowledge. In terms of vehicle vibration research, Hu Qiguo [1] analyzed the time-frequency characteristics of the front and rear wheel excitations of vehicles on non-stable roads. Based on the second type of Lagrangian method, the vibration dynamics equation was established and established with the help of MATLAB/Simulink. The vibration simulation model shows that under the excitation of non-stable roads, appropriately reducing the stiffness of the car seat suspension and rear suspension and increasing the damping of the car seat suspension and rear suspension can improve the ride comfort of the driver. Zhang Jianli [2] In order to study the vehicle vibration caused by the road surface unevenness, the vehicle vibration system was taken as the research object, and the numerical simulation study of the vehicle vibration under the influence of the road surface unevenness was carried out. The generalized virtual work principle is used to establish a four-degree-of-freedom vehicle vibration differential equation system to achieve related vibration research.
Jin Qijun [3] conducted vertical vibration tests under different excitation amplitudes and measured the vibration transmission from the sea floor to the contact surface with the human body to characterize the dynamic performance of the human-chair coupling system. Then, the relative amplitude estimation method is designed for subjective evaluation, and the subjective and objective correlation analysis is carried out. Finally, a parameter that can characterize the vibration isolation performance of the seat is proposed. Zhang Chunhong [4] elaborated on the phenomenon of lateral vibration of the vehicle caused by the driveshaft, explained the evaluation method of lateral vibration from both subjective and objective perspectives, and carried out an in-depth analysis of the test data to determine the mechanism of lateral vibration. Based on the universal joint structure, the force analysis is carried out to identify the causes of the third-order axial circulation force, and the influence factors of the axial circulation force are explored from the four aspects of the arrangement angle, the joint structure, the fitting clearance, and the lubricating grease. Considering the vehicle positioning and control costs, finally determine the fit clearance and the optimization of lubricating grease, and realize the control of the vehicle's lateral vibration problem. Wang Zhijun [5] established a four-degree-of-freedom vehicle vibration model in order to evaluate the impact of vertical vibration and pitch vibration on car ride comfort. Derive the mathematical model through the Laplace transform. Based on MATLAB software, the deduced mathematical model is programmed, and the influence of vehicle vertical vibration and pitching vibration on the excitation of the front and rear wheels is analyzed, and the frequency response of the front and rear axle vibration to the excitation of the front and rear wheels are analyzed. Huang Yiyang [6] used Matlab/Simulink to complete the seven-degree-of-freedom dynamics model of automobile suspension and analyzed its ride comfort with B-level road white noise as an excitation, which provided important theoretical support for subsequent ride comfort research. Tang Tiande [7] established a four-degree-of-freedom automobile two-axle suspension dynamic model and its Simulink simulation model to study the vertical vibration and longitudinal angular vibration of the vehicle body and proposed a method to solve the front and rear suspension amplitude-frequency characteristics by analyzing Simulink time-domain simulation data. A method to convert the amplitude-frequency characteristics of a general dual-axle suspension model with different suspension mass distribution coefficients not equal to 1 under dual input.

Cui Yiwen [8] simplified the structure of a light-duty vehicle into a two-degree-of-freedom vibration model and took this model as an example. In the case of using simple harmonic excitation to simulate the road surface excitation, the dynamic equation was established by the generalized Lagrangian equation, and based on Simulink Process and simulated the dynamic equations of light-duty vehicles. By setting different parameters, the simulation results of each displacement under different conditions are obtained. After analysis and calculation, the simulation results of the model are obtained. There is a certain reference for the optimization design of vehicle dynamic parameters, Wang Dengqiang [9] simplified the vehicle vibration analysis model by analyzing the vehicle vibration form. On this basis, Matlab/Simulink simulation software is used to establish a two-degree-of-freedom vibration simulation model of the vehicle that can be solved, and then the random B-level road spectrum model is used as the excitation source, and the acceleration response of the vehicle body, the vertical direction of the suspension, and the vertical direction of the tire are analyzed. Vehicle comfort indicators such as dynamic load. Li Jie [10] established a 1/2 vehicle 5 degrees of freedom military vehicle vibration analysis model for the random vibration analysis of military vehicles, derived the formula for vehicle random vibration analysis based on the virtual excitation method, and gave the international unit system of absorbed power. Indications that the main indicators and auxiliary indicators of military vehicle random vibration analysis have been determined, and the military vehicle random vibration analysis software has been developed using MATLAB, and the random vibration of a military vehicle has been studied. The results show that the random vibration analysis of military vehicles based on the virtual excitation method is basically consistent with the traditional method, but the method is simpler and more versatile. These studies have carried out a good analysis of the vehicle vibration. Under the MATLAB simulation, the problem has been studied thoroughly, but it is slightly complicated. This article mainly uses a simplified model to analyze the vibration of the dual-mass system of the body and the wheel for analysis. The impact of relevant parameters on vehicle vibration. Jiang Xin [11] simplified the car model into a four-degree-of-
freedom dynamic model of an independent suspension vehicle. Newton's second law is used to establish the differential equation of the car in the driving process. On this basis, a vehicle suspension model based on Simulink software is built and simulated in the time domain and frequency domain, and the white noise function is used as the vibration input of the road surface. At the same time, it analyzes the amplitude-frequency characteristics and proposes a scheme to improve the suspension. At the same time, based on the time domain, the sensitivity analysis of the suspension and tire parameters is done. Hong Dekai [12] studied the vibration characteristics of light trucks based on finite element complex modal analysis and harmonic response analysis.

On the basis of summarizing and analyzing the abnormal vibration manifestations and characteristics of light trucks, according to the various parameters of the truck provided by the company, the finite element model of the truck is established, and the constraint complex modal analysis and harmonic response analysis of the entire truck model are carried out. The low-order vertical natural vibration characteristic parameters of the truck are obtained, and the vertical vibration response of the truck cab position under the action of the wheel's own radial runout excitation is explored. The above analysis results basically determine the cause of the abnormal vibration of the light truck. Based on this, the influence of suspension stiffness and damping parameters on the vibration characteristics of freight cars is further explored.

2. MODELING

This paper establishes a four-degree-of-freedom mathematical model of the automobile through the research of automobile dynamics, and transforms the vibration of the automobile into the process of establishing the model. It has a greater impact on the ride comfort and the grounding of the wheel, and is closer to the car suspension. The actual power of the system.

![Two-degree-of-freedom vibration system for body and wheels](image)

The vertical displacement coordinates of the wheel and the car body are $z_1$, $z_2$, and the coordinate origin is selected at their respective equilibrium positions. The motion equation of the car body and the car in Figure 1 is:

$$
\begin{align}
    m_2 \ddot{z}_2 + C(\dot{z}_2 - \dot{z}_1) + K(z_2 - z_1) &= 0 \\
    m_1 \ddot{z}_1 + C(\dot{z}_2 - \dot{z}_1) + K(z_1 - z_2) + K_t(z_1 - q) &= 0
\end{align}

(1)

In the case of undamped free vibration, the equation of motion becomes:

$$
\begin{align}
    m_2 \ddot{z}_2 + K(z_2 - z_1) &= 0 \\
    m_1 \ddot{z}_1 + K(z_1 - z_2) + K_t z_1 &= 0
\end{align}

(2)

It can be seen from the equation of motion that the vibrations of $m_2$ and $m_1$ are coupled with each other. If $m_1$ does not move ($z_1 = 0$), then

$$
    m_1 \ddot{z}_1 + Kz_2 = 0

(3)$$
This is equivalent to a single degree of freedom undamped free vibration with only the body mass \(m_2\), and its natural circular frequency \(\omega_0 = \sqrt{K/m_2}\). Similarly, if \(m_2\) does not move \((z_2 = 0)\), it is equivalent to the undamped vibration of the wheel mass \(m_1\) with a single degree of freedom, then:

\[
m_1 \ddot{z}_1 + (K + K_t)z_1 = 0
\]

The natural circular frequency of the wheel part is

\[
\omega_t = \sqrt{(K + K_t)/m_1}
\]

At this time, since the body is basically not moving, the two-degree-of-freedom system can be simplified as a single-mass system of the wheel part shown in Figure 2 to analyze the vibration of the wheel part in the high-frequency resonance region.

![Figure 2. Single-mass system for wheel part](image)

After simplification again, the motion equation of mass \(m_1\) at this time is:

\[
m_1 \dddot{z}_1 + C \dot{z}_1 + (K + K_t)z_1 = K_t q
\]

Substituting each complex amplitude into the above formula:

\[
-\omega^2 m_1 z_1 + j\omega C z_1 + (K + K_t)z_1 = K_t q
\]

The frequency response function of wheel displacement \(z_1\) to \(q\) is:

\[
\frac{z_1}{q} = \frac{K_t}{-\omega^2 m_1 + K + K_t + j\omega C}
\]

Divide the numerator and denominator of formula (8) by \(K + K_t\), and substitute the natural circular frequency \(\omega_t\) of the wheel part and the damping ratio \(\zeta_t\) of the wheel part into this formula, then:

\[
\frac{z_1}{q} = \frac{K_t/(K + K_t)}{1 - \left(\frac{\omega}{\omega_t}\right)^2 + j2\zeta_t \omega/\omega_t}
\]

Its amplitude-frequency characteristics are:

\[
\left|\frac{z_1}{q}\right| = \frac{K_t/(K + K_t)}{\sqrt{1 - \left(\frac{\omega}{\omega_t}\right)^2} + (j2\zeta_t \omega/\omega_t)^2}
\]

At high frequency resonance \(\omega = \omega_t\), the rms spectrum of wheel acceleration \(\sqrt{\mathcal{G}_{\ddot{z}_1}(\omega_t)}\) is proportional to the amplitude-frequency characteristics, that is,
\[
\dot{z}_1 = \frac{\omega_t K_t}{(K + K_t) 2\zeta_t}
\]

(11)

It can be seen that reducing the tire stiffness \(K_t\) can reduce \(\omega_t\) and increase \(\zeta_t\), which is an effective way to reduce the acceleration of the wheel part at high frequency resonance; reducing the non-suspension mass \(m_1\) makes both \(\omega_t\) and \(\zeta_t\) increase, and when the wheel part resonates at high frequency, the acceleration of is basically unchanged, but the dynamic load \(m_1 \dot{z}_1\) of the wheel part decreases, which is beneficial to reducing the relative dynamic load. For the dual-mass vibration system, we also need to calculate and analyze the body acceleration \(\ddot{z}_2\), the suspension spring dynamic deflection and the amplitude-frequency characteristics of the wheel relative to the dynamic load to study the relative influence of the parameters of the body and the wheel dual-mass system. Body acceleration \(\ddot{z}_2\) The amplitude-frequency characteristic of \(q\) is:

\[
\dot{z}_2 = \omega \gamma \left( \frac{1 + 4\zeta_2^2 \lambda^2}{\Delta} \right)
\]

(12)

3. SIMULATION

After the research of related models, two simulation studies were mainly carried out in matlab. One is to build a related model of the dual-mass vibration system in matlab to study the root mean square value spectrum \(\sqrt{G_{z_1}(f)}\), \(\sqrt{G_{z_2}(f)}\) and \(\sqrt{G_{a}(f)}\) and the amplitude-frequency characteristics of the corresponding body and wheel dual-mass vibration system \(\dot{z}_1 / q, \dot{z}_2 / \dot{z}_1, \dot{p} / \dot{z}_2\); Choose the body and wheel dual mass system parameters \(f_0 = 1.5Hz, \zeta = 0.25, \gamma = 9, \mu = 10\), the vehicle speed is 20m/s, in matlab Code writing and simulation calculations are carried out in the process to obtain Figure 3 to Figure 4:

![Figure 3. Amplitude-frequency characteristic diagram(a), Amplitude-frequency characteristic diagram(b), Amplitude-frequency characteristic diagram(c)](image)

Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:
Figure 4. Root mean square spectrum spectrum of wheel acceleration(a),Spectrogram of RMS value of vehicle body acceleration(b),Human body acceleration root mean square value spectrum spectrum(c)

From the simulation results, it can be seen that the root mean square value spectrum is proportional to the corresponding amplitude-frequency characteristics, and the curve shape is highly similar, which can explain the accuracy and correctness of the related model. It can also explain that for the dual-mass system vibration system, as long as the acceleration root mean square value spectrum is studied, the corresponding amplitude-frequency characteristic curve can be obtained, and the vibration response of the vehicle body and wheels can be judged.

4. CONCLUSION

This paper mainly studies mechanical vibration. Through continuous simplification, a four-degree-of-freedom model is transformed into a single-degree-of-freedom model. The root mean square value spectrum $\sqrt{G_{x_1}(f)}$, $\sqrt{G_{x_2}(f)}$ and $\sqrt{G_{a}(f)}$ and the amplitude-frequency characteristics of the corresponding vibration system $\frac{|z_1|}{q}$, $\frac{|z_2|}{z_1}$, $\frac{|p|}{z_2}$. This method avoids the lengthy and tedious process of mathematical derivation and differential equation solving, and can easily debug model parameters, and intuitively observe the impact of related parameter changes on the vibration system. It has the characteristics of simple principles, intuitive phenomena, and strong interaction. It has certain application value in subject scientific research and engineering practice.

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