Analysis of the Influence of Characteristic Parameters of Heavy Vehicle Front Suspension to Road Friendliness Based on Virtual Excitation

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Abstract — In this paper, the author researches on the analysis of the influence of the characteristic parameters of heavy vehicle front suspension to road friendliness based on virtual excitation. For increasing speed and riding comfort being paid more attention, the study on road friendliness based on virtual excitation on characteristics of off-road vehicles especially the vehicle without suspension, such as some agricultural and construction vehicles, is becoming an important issue. Taking a type of tractor made in China as an example, the analysis of 2DOF twin-shaft vehicle dynamic model of vehicle without suspension and its natural frequencies were investigated.

Keywords - Influence; Characteristic Parameters; Heavy Vehicle Front Suspension; Road Friendliness

I. INTRODUCTION

The automobile suspension system connects with the body and the wheel. It has functions to cushion the impact of shock, dampen vibration and transmit torque. The research into it is of major significance in regard to both the handling stability and smoothness of automobiles. However, the automobile suspension system is a multi-body system and the motion relationship among the parts is very complicated, so it brings many difficulties to compute the various characteristics with traditional computation methods. The Automobile suspension kinetics and dynamic simulation has been a very important task in automobile design and development and it provides a rapid and effective method to design automobile suspension. Zhao’s [1] research object of this thesis is a front suspension system of some heavy duty automobile and it is double wishbone suspension system. His paper points out the components and designs requirements of the front suspension system as well as the functions and selection criteria of assemble. Based on that, various parameters of assemblies that are needed for modeling are determined such as mass parameters, Kinetic parameters, Mechanic parameters and so on. According to the corresponding items of data, the characteristic curves of them are also established in ADAMS. On this basis, Dou’s paper [2] sets up a three-dimensional model for double wishbone suspension system in the use of ADAMS/car, sets various parameters of simulation and makes Kinetic and Mechanic simulation testing of this model. According to the results of simulations, this thesis analyzed performance parameters of front suspension system in ADAMS/Postprocessor, such as camber angle, caster angle, caster offset, Kingpin inclination angle, lateral Migration offset, toe-in angle, steering angle, tread, brake pitching number, accelerating lift number, suspension tangent stiffness, roll stiffness and so on. All these parameters of suspension system, which are in the common range of jumper (-50 ~ 50mm), have great impact on handling stability and smoothness of automobiles. The characteristic curves of these parameters are drawn along with the variation of jumper. Conversely, these parameters are analyzed based on the characteristic curves. This simulation of double wishbone suspension and the result of it can provide reliable reference for making a rapid and right decision in the suspension simulation program.

Park’s [3] research carries out kinematic simulation and analysis for the front McPherson suspension, based on dynamic theory and vehicle handling and stability, and applies Adams/Insight module in researching and optimizing its structure parameters; meanwhile, the research develops the template of rear twist beam suspension, which enriches the template library of suspension in Adams/Car. Furthermore, the research establishes a virtual prototype model of vehicle and carries out a test simulation of vehicle handling and stability so as to compare the vehicle handling and stability performance before and after the optimal front suspension. In Zhang’s [4] research, the researcher applied Catia software in establishing a three-dimensional model of the front McPherson suspension, and used Adams/Car to establish its parameterized model. The researcher also used Solidworks to establish the twist beam and imports the beam into the finite element analysis software for meshing according to the principle of flexible body modeling; then, the beam was imported into Adams/Car through Mode Neutral File; thus, the template of twist beam of rear suspension was obtained. On the basis of these achievements, Nam [5] sets up the virtual prototype models of the rear suspension, steering system, the front lateral stability rod and...

In Han’s [6] paper, the author carried out the kinematic simulation analysis for the front suspension, and verified the correctness of the model from the kinematic point of view. The author also identified the factors that have impacts on the vehicle handling and stability according to the simulation results of the front suspension, and then applied Adams/Insight in studying the key hinge point coordinates of the front suspension. Thus, the extent and trends of these hinge point coordinates for the wheel alignment parameters were obtained. Test simulation was used to derive the optimal structural parameters and optimize the kinematics of the suspension by a multi-objective and multi-variable optimization.

II. FRAMEWORK OF VIRTUAL EXCITATION

With the growing popularity of the car, people no longer meet the ordinary car function of instead of walk, more and more people pursuing for individuality. In order to satisfy people's pursuit of speed and stimulate, an assumption that designs a new three wheels sport car was presented. In modern automobile design, suspension structure form and its performance directly influences the vehicle performance. Having a good suspension, the vehicle will be excellent.

When designed a automobile car, the assembly angles with horizontal plane of lower control arm and upper control arm are the best influential design variable on each appraisable target of suspension’s performance. This two design variable can change not only the variation magnitude but also the variation trend. The length of tie rod has great influence on toe angle. Optimization design was done on this suspension, and the optimized aim considered not only the variation magnitude, but also the variation trend’s influence on handling stability. The optimization results meet the demands of suspension design and the targets of suspension’s performance achieved their ideal variation range. Basing on the results of handling stability simulation and analysis test, it can be known that roll bar and the height of centroid are the best influential design factors on the handling stability. Using roll bar and making the centroid lower can ameliorate handling stability commendably, and moving the centroid forward and increasing front suspension’s stiffness also can ameliorate handling stability.

With the rapid development of automobile industry, the vehicle performance requirements in handling stability and ride comfort are also increasing. The suspension system plays a vital role on the stability, comfort and security et al. The conventional leaf spring type non-independent suspension, mainly used in some hardcore off-road vehicles and commercial vehicles, has many shortcomings such as heavy weight, high stiffness, poor comfort et al. While the independent suspension system, mainly used in passenger cars, possess many advantages: 1) Relative light weight in unspring mass, which can reduce the body shock and improve the traction of the wheels; 2) softer spring can be used to improve the ride comfort; 3) the position of the engine and the vehicle center of gravity can be lowered to improve the vehicle handling performance. From the view of suspension performance, the independent suspension is better than non-independent suspension. However, the independent suspension is rarely applied on the larger commercial vehicles due to its drawbacks such as complex structure, high cost, inconvenience to repair and poor bearing capacity. Figure 1 shows the 3D model of heavy vehicle front suspension which is the research object.

The vehicle suspension system is one of the key parts of vehicles. Its performances can directly influence the steering stability as well as the ride comfort and so on. Suspension is one of the important assemblies in modern vehicle. The main function of a suspension is to transfer forces and torques and to regulate the relative motion between the body and the wheels, at the same time to abate the impact to vehicle and to damp the vibrations from the road, so that the vehicle could run smoothly. The suspension system has directly effects on vehicle performance, especially handling stability, the ride comfort, the turning ability, and the life cycle of the tires etc. The double-wishbone suspension, which was widely used in vehicle now, is one kind of the independent suspensions. Figure 2 shows the architecture of each part in front suspension.

Figure 1. The 3D model of heavy vehicle front suspension

Figure 2. The architecture of each part in front suspension
III. THE ALGORITHM

The basic equation of the proposed algorithm of relation between stress and load is given as follows equation (1):

\[
\begin{bmatrix}
\sigma_x \\
\sigma_y \\
\tau_{xy}
\end{bmatrix} = T \bar{Q}_k
\]

(1)

The transmit torque \( T \) represents the transfer matrix of coordinate.

\[
\begin{bmatrix}
A_{N_x} \\
A_{N_y} \\
A_{M_x} \\
A_{M_y}
\end{bmatrix} = N + Z \begin{bmatrix}
A_{N_x} \\
A_{N_y} \\
A_{M_x} \\
A_{M_y}
\end{bmatrix}
\]

(2)

In equation (2), \( \alpha \), \( \beta \), a, b, c represent the coefficients of different dimensions.

The one of the objective functions, can be expressed as follows, \( f(X) = f(x_1, x_2, \ldots, x_n) \) 

Subject to \( g_j(X) \leq 0 \quad j = 1, \ldots, m \) 

\( h_k(X) = 0 \quad k = 1, \ldots, m_k \) 

\( x_i^l \leq x_i \leq x_i^u \quad i = 1, \ldots, n \)

Rewrite again Eq. (4) as

\[
\hat{f}^a_H(x) = \frac{1}{\Gamma(1+\alpha)} \int_{-\infty}^{\infty} f(t) (t-x)^{a}(dt)^a
\]

(8)

\[
\hat{f}^a_H(x) = \frac{1}{\Gamma(1+\alpha)} \int_{-\infty}^{\infty} f(t) g(x-t)(dt)^a
\]

(9)

\[
\partial_j(C_{ij} \partial_k u_i + e_{ij} \partial_k \phi) = \rho \ddot{u}_i
\]

(10)

The linear equation can be expressed into the following simplified forms:

\[
\begin{align*}
L(\nabla, \omega) f(x, \omega) &= 0 \\
L(\nabla, \omega) &= T(\nabla) + \omega^2 \rho J
\end{align*}
\]

(11)

\[
\sum_{m=-1,2,3,n=-1,3,\ldots} \frac{J_m(m \pi)}{m} \sin(m\pi - \alpha_1 - \frac{4\pi}{3})
\]

(12)

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\]

(9)

\[
\partial_j(C_{ij} \partial_k u_i + e_{ij} \partial_k \phi) = \rho \ddot{u}_i
\]

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The linear equation can be expressed into the following simplified forms:

\[
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L(\nabla, \omega) &= T(\nabla) + \omega^2 \rho J
\end{align*}
\]

(11)

\[
\sum_{m=-1,2,3,n=-1,3,\ldots} \frac{J_m(m \pi)}{m} \sin(m\pi - \alpha_1 - \frac{4\pi}{3})
\]

(12)

Then we have:

\[
\sin m(\pi - \alpha_1) + \sin m(\pi - \alpha_1 - 2\pi / 3)
\]

(13)

\[
\cos m(\pi - \alpha_1) + \cos m(\pi - \alpha_1 - 2\pi / 3)
\]

(14)

When m is not the integral multiple of 3, the value is 0, then

\[
u_p = \frac{M E}{6} \sin \omega t \pm
\]

(15)

\[
\frac{E}{\pi \sum_{n=3,6,\ldots} \sum_{m=1,3,\ldots} J_n(m \pi) \sin [(m F + n) \omega t]}
\]

(16)

So the equation (5) can be expressed as equation.
IV. EXPERIMENT RESULTS AND DISCUSSION

In the experiment, first of all, through the actual measure chassis, establish the virtual prototype model of the double wishbone independent suspension, and then optimizing the structure of torsion bar size to improve the stiffness of the double wishbone front suspension, the suspension of the overall design requirements. On the basis of this, we put forward a kind of innovative design of the double wishbone suspension, broaden the suspension stiffness change space, and optimizes the suspension stiffness on this based. In view of the double wishbone independent front suspension tire wear serious problem, the analysis of the sensitivity of various parameters on tire wear, selected comprehensive sensitivity parameters as design variables of optimization, and the suspension of the wheel camber Angle, toe Angle and wheel sideslip quantity as the main performance parameters. Using radial basis function (RBF) to construct the response surface approximation model, through the problem of multi-objective genetic algorithm for optimization, reducing tire wear effect. The optimization and the improved three double wishbone front suspensions respectively carry on the same pure electric bus chassis model, build the virtual prototype model of the test vehicle of chassis, respectively according to national standard "test method for vehicle handling stability" requirements, on the national standard of steady turning experiment and steering portability. Figure 3 shows the schematic of the grid arrangement. Figure 4 shows schematic of the computing domain and coordinates arrangement.

Considering the number of evaluating indices of handling performance is too many, the Principal Component Analysis (PCA) method is applied for reducing dimension processing. The evaluation indices are reduced from 21 to 5 after calculation. Then, a chassis parameter design is processed aiming at matching and optimizing the ride and handling performance using the indices obtained by PCA dimension reduction. The result is satisfied with requirement of vehicle travel performance. Multiple surrogate models are applied in suspension and steering matching design. The applications of second and third order Response Surface Model (RSM), Kriging Model (KRG) and Radial Basis Function Neuro Network Model (RBF) in chassis performance matching problem are analyzed and compare respectively. In case of suspension and steering matching design problem, results show that each surrogate model is able to gain an optimal design. However, a surrogate model with better prediction accuracy does not certainly obtain a better design result. Thus application of multiple surrogate models should be considered in engineering problems. Figure 5 shows the orientation result of the test vehicle. Figure 6 shows ADAMS result of characteristic parameters of heavy vehicle front suspension to road friendliness based on virtual excitation.
Figure 6. The ADAMS result of characteristic parameters of heavy vehicle front suspension to road friendliness based on virtual excitation

Three conclusions can be put forward from the range of stiffness and damping in simulation:

1. The influence of suspension parameters to plumb vibration of vehicle body: the mean square root of plumb acceleration of vehicle body is reduced with increasing damping or reducing stiffness of front suspension.

2. The influence of suspension parameters to pitch vibration: the mean square root of pitch vibration angle acceleration is increased with increasing stiffness, while the mean square roots of pitch vibration angle displacement of vehicle body and dynamic deflection of front suspension are reduced with increasing stiffness. It can be found that the smaller front suspension damping, the more prominent influence of suspension stiffness to above parameters.

3. The influence of suspension parameters to dynamic deflection of front suspension and dynamic loading of front wheel. With the increasing suspension damping, the mean square roots of dynamic loading of front wheel is decreased until it begins to increase after.

In this paper, vibration characteristics of vehicle with front suspension and without were compared. The simulation results showed that the mean square roots of body plumb acceleration was reduced 5%, the mean square roots of pitch vibration angle acceleration and angle displacement can be reduced 45% and 3.4% respectively, and the amplitudes of these parameters were all reduced, which improved the driving performance of the vehicle and the driver’s riding comfort.

V. CONCLUSIONS

In this paper, the author researches on the analysis of the influence of the characteristic parameters of heavy vehicle front suspension to road friendliness based on virtual excitation. The optimization results meet the demands of suspension design and the targets of suspension’s performance achieved their ideal variation range. Basing on the results of handling stability simulation and analysis test, it can be known that roll bar and the height of centroid are the best influential design factors on the handling stability. Using roll bar and making the centroid lower can ameliorate handling stability commendably, and moving the centroid forward and increasing front suspension’s stiffness also can ameliorate handling stability.

For increasing speed and riding comfort being paid more attention, the study on road friendliness based on virtual excitation on characteristics of off-road vehicles especially the vehicle without suspension, such as some agricultural and construction vehicles, is becoming an important issue.

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