The influence of the steering wheel angle on vehicle handling stability

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Abstract

Based on the ADAMS software, we established a whole vehicle model to study its handling stability. It includes the front suspension system, the rear suspension system, the steering system and four wheels. After the simulation trials, we analyze the vehicle speed, the steering radius and the yaw angular velocity. The influence of steering wheel angle on the vehicle speed is not big, but the influence on the steering radius and the yaw angular velocity is obvious. The results accord with the actual steering motion and can be a reference for researchers on the study of handling stability.

Keywords: ADAMS, the whole vehicle model, the handling stability, the steering wheel angle

1 Introduction

Nowadays the automobile is becoming more and more common and various performance of vehicle has gradually attracted people's attention, such as the economy, the ride performance and the handling stability. With the development of the automotive technology and the increase of the freeway, the vehicle speed is greatly improved. The handling stability of vehicle in high speed directly affects the safety of automobile [1] and is an important index in the evaluation of the car's performance. Therefore, the experiment on the handling stability has become an essential section in the vehicle research and development [2]. The main research of the handling stability is the control of the driver and the attitude of the vehicle in motion state [3], related to various road impacts. In such a dynamic system with continuous change, the impacts of the road transfer to the vehicle body and the steering wheel through the wheels and the suspension. As a result, a complex mechanical system is formed [4].

In analysis of traditional vehicle dynamics, the target system mathematical model is generally established through the algebraic equation and the differential equation. But to solve the model, it will take a huge working load and a long working time. Today the computer technology is highly developed. With the help of the powerful computing capability of computer, we can greatly improve the speed of solving mathematical model [5].

At present, the computer application in the automobile simulation test has become so common that simulation experiment has been inseparable from the computer. Based on different calculation method and modeling method, there is a large number of computer simulation software [6], such as ADAMS (Automatic Dynamic Analysis of Mechanical Systems), RecurDyn (Recursive Dynamic), CarSim and veDYNA. And the application of ADAMS is the most common. According to the statistics in the reference [7], the total sales of ADAMS is nearly $80,000,000, occupied 51% international market share of mechanical system dynamic simulation analysis software.

The study of vehicle handling stability has been developed from two linear degrees to multi-degree [8-11]. Domestic research focuses in the field of passenger car. The method of modeling, simulating, testing and evaluating is relatively mature, which has formed a relatively perfect technology system [12]. There are many factors affecting the vehicle handling stability. And the current research mainly concentrated in suspension stiffness, tire stiffness, load, CM (center of mass) position and steering speed, etc., and has made much research achievements [13].

In the process of actual driving, cornering condition is a special case. The unreasonable steering wheel angle can even cause traffic accidents in high speed. Based on ADAMS, the paper discusses the influence of the steering wheel angle on the handling stability, and analyses the characteristic curve of stable steering state and unsteady state. The results of simulation will provide theoretic reference and technical support for the vehicle design and the handling stability test.

2 The theoretical basis of the modelling

After the model is built in ADAMS, the software can automatically establish and solve the equation on the basis of the constraint relationship between the components and the parts in the model. The theoretical basis of the dynamics and kinematics analysis in ADAMS is built on a series of formulas.

A. Establishing the dynamics equations and solving.

The overall coordinate system and the local coordinate system used in ADAMS are rectangular coordinate system. The generalized coordinate system has a great influence on the simulation speed to the simulation model of dynamic equation. The ADAMS software uses the mass center of rigid body in the Cartesian coordinates and the Euler angle reflecting the rigid body's azimuth as the generalized coordinates. And the Lagrange multiplier method is adopted to establish the motion Equations of the system in the background processes. The Equations are as follows.

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$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}}\right)^T - \left(\frac{\partial T}{\partial q}\right)^T + \phi_q^T \rho + \theta_{\dot{q}}^T \mu = Q . \qquad (1)$$

The holonomic Equation is:

$$\phi(q,t) = 0 . \qquad (2)$$

The non-holonomic Equation is:

$$\theta(q,\dot{q},t) = 0 . \qquad (3)$$

The meanings of symbols in Equations (1-3) are: T- system function; q- the generalized array of system; Q- the generalized force array; ρ - the Laplace multiplier array corresponding to the complete constraints; μ - the Laplace multiplier array corresponding to the non-holonomic constraints.

B. The kinematics analysis.

The object of kinematics analysis study is the change of system location over time, regardless of the cause of the position change (such as power factor). Therefore, the focus is the position, the velocity and the acceleration in the kinematics analysis, so solving system constraint equation is necessary. The constraint equation is as follows.

$$\Phi(q,t_n) = 0 . \qquad (4)$$

The solving process of Equation (4) is introduced in reference [14] in detail. So the determination of the constraint reaction force at t_n, can be made with a multiplier Lagrange Equation.

$$\left(\frac{\partial \Phi}{\partial q}\right)^T \lambda = \left[-\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}}\right)^T + \left(\frac{\partial T}{\partial q}\right)^T + Q \right] . \qquad (5)$$

The meanings of symbols in Equation (5) are same with meanings in the Equations (1), (2), (3).

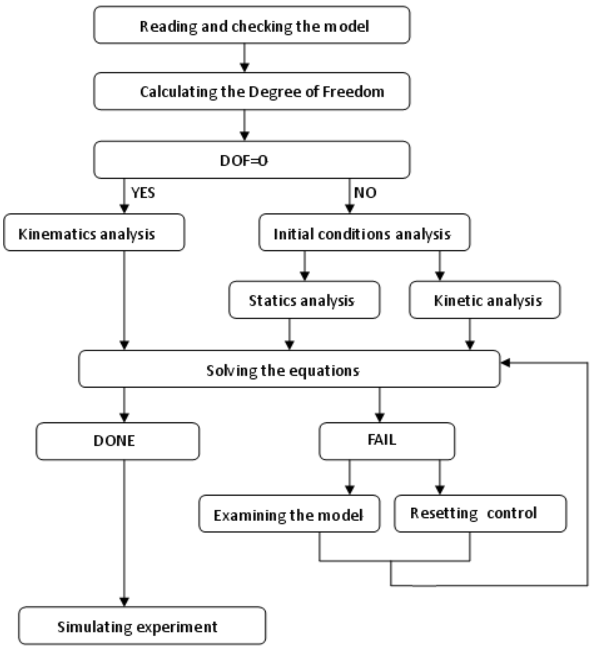

FIGURE 1 The flow chart of the analysis and calculation in ADAMS

In addition to the above Equation, there are also statics analysis, analysis of the initial conditions in the analysis and calculation of ADAMS. They are all the basis of the calculation and analysis of the simulation system. Generally speaking, after the simulation model is built, the degree of freedom is calculated. If the degree of freedom is 0, the system does the kinematics analysis directly. Otherwise, the system will determine the statics or the dynamics according to the initial conditions. Then the solving of equation is done. If the solving is successful, we can take the next step of simulation test, and maybe the solving fails because of the equation numerical divergence. At this moment, it is necessary to check the constraints of the model or reset the control parameters of the simulation until the solving is successful. The flow chart is as follows shown in Figure 1.

3 Building the simulation model

A. The simplification of the vehicle model.

A vehicle often involves tens of thousands of parts and components, and can be affected by a variety of random force and moment in the process of driving, even by the coupling effect between different systems. Therefore, to establish a vehicle model is a huge work. If the simulation model is established exactly according to the actual structure and the working condition, the difficulty of modeling will increase and the modeling cycle will extend. And it also may cause the failure of the simulation test, and affect the whole design process. Therefore, before the simulation model is set up, it is crucial to analyze the research object, to abstract and simplify the system, to ignore the small parts. This paper focuses on the vehicle handling stability, so appropriate simplifying is done as follows:

1) The transmission system is omitted such as the engine, clutch, transmission, universal transmission device, the main reduction gears and the half shaft system etc.

2) There are also other parts and components which are omitted, such as the cockpit, the engine bay, the luggage compartment, the vehicle body and its ancillary facilities, etc.

3) The four wheels, the steering system and the suspension system are reserved.

4) We treat the whole vehicle as a mass point, which has the whole mass of the vehicle and is located in the center of the vehicle mass.

In the process of modeling, attention should be paid to the choice of tire model. The dynamic simulation in ADAMS assumes all forces are transmitted through the tire when the vehicle is in the running process. The lateral force of tire has directly effect on the handling stability of vehicle, and the tire lateral force changes with the wheel vertical load, so the influence of tire on handling stability is dynamic[15]. Therefore, the tire model selection is the key in dynamic simulation of vehicle. The tire model affects the reliability and accuracy of the simulation, so it is necessary to pay enough attention on the tire model. In this paper we choose the UA tire model according to the need of the simulation experiment.

C. Building the whole vehicle model.

We can obtain the whole vehicle model after setting and modeling environment, creating design points and components, applying constraints to the vehicle model. And the model contains the front suspension system with double wishbone, the rear suspension system with inclined arms, the steering system, four wheels and the ground matching with the wheels.

4 Debug simulation model

A. Determine the steering wheel input function.

After the establishment of the vehicle model, the steering wheel angle is applied in the steering wheel and the torque is applied in the rear wheels. The function expression of steering wheel angle is shown in Equation (6) and the curve is shown in Figure 2.

The step function expression of steering wheel angle is:

step (time, 2, 0, 4, 110d). (6)

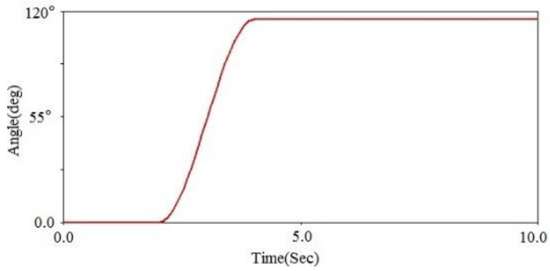

FIGURE 2 The curve of steering wheel angle input

According to the vehicle steering characteristics, at the beginning of the steering motion a small torque is applied in the drive wheels, and then the torque increases gradually. The torque curve is shown in Figure 3 and the function expression of the driving torque is shown in (7).

STEP(time,0,0,6,30000)+
STEP(time,6,0,400,1200000) . (7)

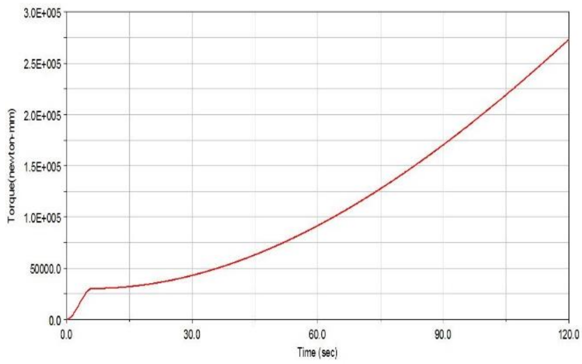

FIGURE 3 The torque of driving wheels

B. Self examination and calculation of the simulation model.

When the dynamic model is completed, ADAMS can calculate the degrees of freedom of the test model, analyze and debug the dynamic performance of the model automatically. The whole vehicle model established in this paper includes 14 degrees of freedom, 21 parts and four wheels.

C. Establish the vehicle steering characteristic curve.

In the simulation test, we need the corresponding curves of parameters to analyze the vehicle handling stability. The components and parts have some built-in functions in the ADAMS software, but it does not meet the demand of this article. We can edit necessary function using the function editor.

The function expression of steering radius is:

R= (V (Chassis.cm)/WY (Chassis.cm))/1000 . (8)

Some explanations about (8) are as follows. The unit of R is meter. The functions V (Chassis.cm) and WY (Chassis.cm) are generated automatically in ADAMS, which represent the car's velocity and angular velocity. The number 1000 is for the sake of unit conversion. Therefore, the unit of steering radius is meter.

The function expression of velocity is:

V=SQRT(VX(Chassis.com)**2 +
VZ(Chassis.com)**2)*3.6/1000 . (9)

In the simulation model, X axis and Z axis form a horizontal plane, and this is the motion plane of the simulation model. VX (Chassis.com) and VZ (Chassis.com) represents the speed of the body in the X axis and Z axis separately, which are automatically generated. Obviously, the vehicle's speed is the speed synthesis of the velocity along X axis direction and the velocity along the Z axis direction. As a result, the unit of the velocity is km/h.

5 The influence of the steering wheel angle on vehicle handling stability

According to the need of the research, we can carry out the experiment through the above debugging and related setting with the whole vehicle dynamics model. In this paper, we design three experiments, in which the steering angle is 110°, 120° and 130° respectively and the steering wheel angle adopts the step input function in Equation (6). The names of the three experiments are 110deg, 120deg and 130deg respectively. After the simulation test, we can obtain the corresponding experimental data and curves in the ADAMS/Postprocessor module. The next is analysis of the three simulation test through comparing the curve.

There are three velocity curves of the tests in Figure 4. From the overall trend of curve in the Figure 5, we can see that the velocity is increasing as the time is changing. In the time from 0 second to the 45th second, the change of the curve is small and the car is running at a stable state with low speed. After the 45th second, the slope of velocity curve is becoming bigger, and the speed increases quickly, especially after the 97th second. In fact, the sharp increase of speed could threaten the traffic safety. By comparing the three curves we can know that in the first 80 seconds, steering wheel angle has little impact on the velocity. After the 80th second, the velocity value is bigger with smaller steering wheel angle input.

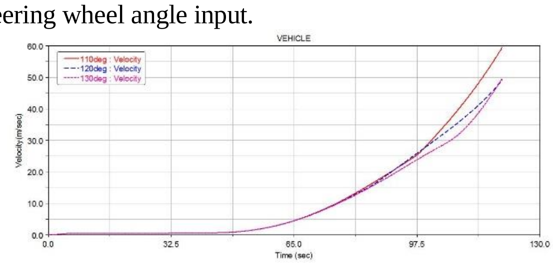

FIGURE 4 The curve of velocity

The radius curves of the three simulation tests are shown in Figure 5a. In the first 110 seconds, the steering radius is relatively stable, while the steering radius occur a drastic change in some moment after 110 seconds.

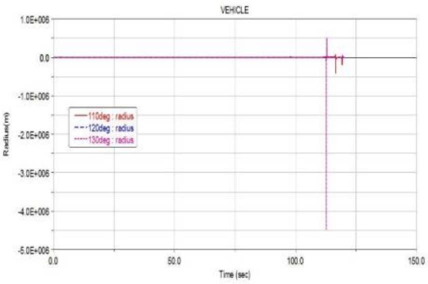

FIGURE 5a The curve of steering radius (t=0~120s)

In Figure 5b, we can see the change of the radius from 0 second to the 10th second, and the steering wheel is converting to the specified angle in the period of 2-4 seconds. In the trial 130deg with 130 degree steering angle, the steering radius curve appeared a downward angle at the beginning of turning. This may be due to the impact of the coupling between certain constraints in the simulation model. Between the 2nd second and the 4th second, the radius curve produces an oscillation waveform: firstly the curve downs to form a smaller trough, then steps up to form a high wave, and then fells back quickly. Thus, in the process of steering wheel input, the response of turning is more sensitive when the steering wheel angle is greater. And the change range of steering radius is smaller when the steering wheel angle is smaller, so the car's steering is stable.

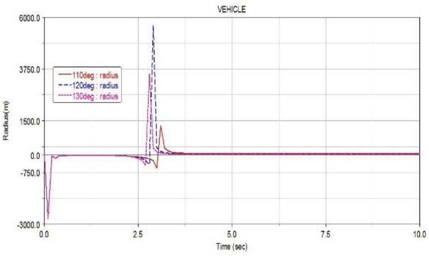

FIGURE 5b The curve of steering radius (t=0~10s)

Figure 5c indicates that the steering radius curve remains slightly increasing in the time stage of 5-70 seconds. It shows that the car has the understeer characteristic, which is a kind of safe working condition. From the numerical point of the curve we know that the radius is smallest in the test 130deg and the radius is biggest in the test 110deg. This suggests that in the test with smaller steering wheel angle input the car steering radius is bigger and the handling stability is better.

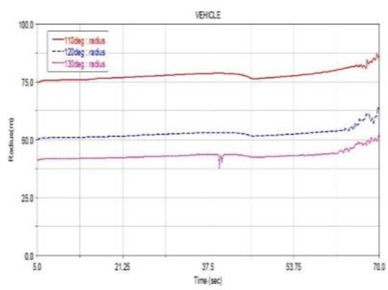

FIGURE 5c The curve of steering radius (t=50~70s)

The change of steering radius at time stage of 50-120 seconds is shown in Figure 5d. On the whole, the steering radius curve is smooth between the 50th second and the 90th second. After the 90th second the three curves appears huge change, especially when the simulation time is close to the 120th second the three curves all appeared severe vibration. From the Figures 5a and 5d, we know that the radius curve downs and appears thin sharp protuberance when time is equal to the 112th second in the test of the 130deg. This indicates the car's handling stability performance is good in the 50-90 second. At the end of the turning, the radius curve appears a significant change and the steering motion turned into an unstable condition.

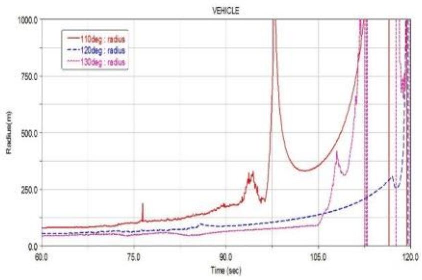

FIGURE 5d The curve of steering radius (t=50~120s)

In Figure 6 we can see the change of the yaw angular velocity. The yaw angular velocity is an important evaluation index of vehicle handling stability. On the whole, the value of the yaw angular velocity increases with time. At the early stage of steering motion, the curve of yaw angular velocity is very smooth. From the 50th second to the 90th second, the curve still has a very strong continuity with the former curve; and it is still in a rising trend, while the waveform appears a saw tooth shape. From the 90th second to the 120th second, the yaw angular velocity curve generates an obvious and significant change: the size and the direction of the curve's slope change evidently and the most obvious change appears in the test 130deg, which has the biggest steering angle input within the three experiments. From the above analysis we can see that under the steering wheel angle step input, the first and the middle stage of steering motion is a stable condition; at the end of the steering motion, the handling stability decreases and abnormal characteristics may be produced.

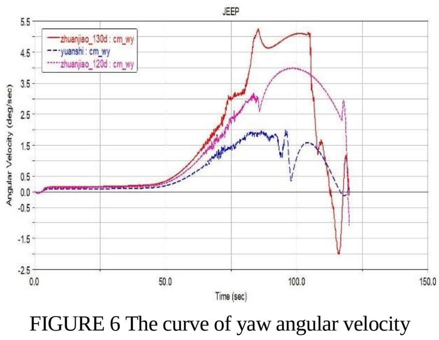

FIGURE 6 The curve of yaw angular velocity

Then the three trials are analyzed. The shapes of three yaw angular velocity curves are similar. In the trial 130deg, the steering wheel angle input is 130 degree and the angle is biggest within three trials. In the first stable period the yaw angular velocity of the trial 130deg is bigger and in the later period of steering motion the change is also the bigger. It indicates that: when the steering wheel angle input is small, the yaw angular velocity curve is more ideal and the handling stability of vehicle in steering condition is better. Therefore, in the actual steering motion, the steering wheel angle should decrease to the appropriate value after a certain period of time in order to increase the stability of the car.

6 Conclusion

The performance of vehicle handling stability has an important effect on the safety of a driving vehicle. In this paper, we construct a whole vehicle simulation model based on the ADAMS software. In the simulation test, the input of the steering wheel is a step function. In order to investigate the handling stability, we do three trials with different steering wheel angle. Then the analysis is done with the vehicle speed, the steering radius and the yaw angular velocity. Finally, the conclusions are obtained as follow.

1) The increase of vehicle velocity is slow at the earlier stage of the steering, while the change of the velocity is quick in the last period. As a result, the vehicle has a high speed in the last period of the steering, which maybe cause dangerous. Different steering wheel angle has a small influence on the velocity in the three experiments. But there has some evident difference in the velocity curve in the last period of the steering: the vehicle speed is higher when the steering angle is smaller.

2) The steering radius of the vehicle is becoming bigger gradually in each test, which demonstrates the vehicle has understeer characteristic. The understeer characteristic is a safe condition. The influence of the steering angle on the radius is not same at different steering stages. In the three experiments, the steering radius is bigger in the test with smaller steering angle. At the beginning of the steering, the fluctuation of steering radius is less in the test with smaller steering angle and the vehicle is in a more steady condition. At the middle stage of the simulation, the radius has a little increase and the radius is bigger in the test with smaller steering angle, which has better character of the handling stability. At the last stage of the simulation trial, the radius is vibrating and the vibration is less in the test with smaller steering angle. From the analysis, we know that the smaller steering angle is better to the vehicle. So when a car is in the process of steering, the angle of the steering wheel should not be too big, especially at last stage of the steering. In the last phase of the steering, the driver should reduce the steering angle in order to get better handing stability and to avoid the dangerous condition.

3) The steering angle has obvious influence on the yaw angular velocity, especially at the last stage of the simulation. In the test with smaller steering angle, the numerical value of the yaw angular velocity is smaller and the change is less, so the test has better handing stability.

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