Analysis of the Factors influencing Vehicle Handling Stability through Modelling, Equations and Python

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Abstract. Car handling stability means that the car can drive according to the given direction of the driver through the steering system and steering wheel when the driver does not feel too nervous or fatigue. Besides,when the car subject to external interference (uneven road, side wind, cargo or passenger partial load), it can resist interference and maintain a stable driving performance. This is very important to ensure driving safety and driving comfort. This paper mainly through the establishment of two degrees of freedom model, sets out a system of equations, solves the analysis of the change of each angle of inclination on the influence of manoeuvring stability, selected vehicle speed, used python to analyze the relationship between vehicle speed and angle of inclination, so as to analyze the relationship between the angle of inclination and the return torque and manoeuvring stability, and try to use ADAMS/CAR to form a whole vehicle dynamics model. Through the analysis of the data and results, it is achievable that the whole vehicle multi-body system could be optimized, so that the vehicle's handling stability can be significantly improved.

Keywords: Handling stability, automobile steering system, emulation, modeling experiment

1. INTRODUCTION

With the rapid development of the automobile industry and the increasing improvement of people's living standards, the automobile has become an important means of transport for people's daily travel. In recent years, the frequent occurrence of traffic accidents has made road safety an issue of widespread concern in society. For this reason, car designers have begun to focus on designing the active safety of cars. Active safety means that the car has a performance that avoids accidents as far as possible in all conditions, such as reliability, environmental visibility, manoeuvring stability and acceleration and braking. The handling stability of a car not only affects the driver's proficiency and convenience in handling the car, but is also an important indicator to determine whether the car is safe to drive at high speed, and is one of the main influencing factors of active safety.

As a complex multi-degree-of-freedom non-linear continuum vibration system, the key to analyzing and evaluating the handling stability of a car lies in the establishment of an ideal dynamics model. With the development of virtual simulation technology, it has become possible to establish a complex multi-degree-of-freedom car dynamics model, providing an effective way to study the handling stability of a car. Simulation software, programming software and simplified vehicle models can also be used for computational solution analysis.

In this paper, the vehicle model is established in ADAMS/CAR, and the handling stability of the vehicle is simulated and evaluated according to the requirements of national and international standards, to understand the steady-state steering characteristics and transient steering characteristics related to the vehicle's handling stability, and then the height of the vehicle's centre of mass, the vehicle mass, the lateral deflection stiffness of the tyres and some positioning parameters of the front wheels are used as parameters for optimizing the design of the vehicle. The vehicle was then optimized using the centre of mass, mass, tyre lateral deflection stiffness and some front wheel positioning parameters. The two-degree-of-freedom model and the modified two-degree-of-freedom model can be used to calculate and analyse the relationship between camber, speed, lateral deflection stiffness, vehicle length and mass on the handling stability [1]. It is also possible to use python and Matlab programming to plot the relationships in order to visualize them more easily and optimize them.

2. METHOD

2.1. Research and evaluation methods for manoeuvring stability

2.1.1. Open circuit control systems

A feedback-free control system that only follows established operational inputs and does not allow for driver intervention and corrections. The open circuit control system is only related to the vehicle structure and parameters and is an inherent characteristic of the vehicle, which can be analyzed and predicted by mathematical and theoretical models.

2.1.2. Closed-circuit control systems

A human-vehicle system that treats the human and the vehicle as a unified whole and considers a control system with closed-loop feedback from the human and the vehicle. The principle of human-vehicle closed-loop control is explained; the driver decides the driving strategy according to the road, traffic, weather and other driving environment, and controls the car by manipulating the steering, braking, throttle and other car mechanisms to produce real-time movement in the driving environment. The car then feeds back to the driver the changes in working conditions after the driver and external interference inputs, and the driver carries out closed-loop control according to the feedback information. Closed-loop control systems are closer to real-world driving and truly reflect the stability of real-world vehicle operation; however, due to human intervention, reproducibility and objectivity are not as good as open-loop systems. It can only be evaluated in the presence of a vehicle and cannot be predicted through theoretical analysis and calculation.

2.1.3. Subjective evaluation

Evaluation through the driver's perception of the various driving conditions of the vehicle. Subjective evaluation has a large relationship with the driver, the evaluation results vary greatly between different people, and it does not reflect the relationship between the structure and performance of the vehicle.

2.1.4. Objective evaluation

The physical quantities characterizing the stability of the vehicle, such as speed, angle of rotation, torque, angular velocity of the transverse pendulum, lateral acceleration, lateral deflection angle, etc., are measured by means of measuring instruments and evaluated according to the measurement results. The objective evaluation method differs from normal driving conditions and cannot truly and fully reflect the stability performance; however, through objective measurements, it can guide vehicle design and optimize performance through theoretical analysis. The objective evaluation method is a switching test method determined through years of subjective evaluation, and the physical quantities detected are also those related to the subjective evaluation term.

The subjective and objective evaluations can be integrated to assist in the evaluation and determination of the handling stability performance, with the results of the subjective evaluation ultimately prevailing.

2.2. Common test methods for handling stability

After years of automotive research, the industry has adopted standardized test methods for the study and evaluation of handling stability. Standards such as GB/T 6323 have clearly defined the specific test methods [2]. The test methods for handling stability are partly open-loop testing (objective evaluation) and partly closed-loop testing (subjective evaluation, objective testing) , such as response under steering angle step input, straight-line driving performance, steering lightness, steering manoeuvrability, return to squareness, steering stability in intermediate positions, frequency response characteristics are all open-loop tests, using objective evaluation methods for the evaluation of the vehicle. Typical driving conditions such as snake winding, single shift and double shift tests are closed-loop tests, where the driver corrects the vehicle's trajectory in real time and the test

combines subjective and objective evaluations (maximum speed that can be safely passed) to assess the stability of the vehicle.

2.3. Automotive two-degree-of-freedom systems

Differential equations for automotive two-degree-of-freedom systems are recognized as

$$\begin{aligned}(k_1+k_2)\beta+\frac{1}{u}(ak_1-bk_2)\omega_r-k_1\delta=m(v+u\omega_r)\\(ak_1-bk_2)\beta+\frac{1}{u}(a\text{^}2k_1+b\text{^}2k_2)\omega_r-ak_1\delta=Iz\omega_r\end{aligned} \tag{1}$$

where K1, K2 are the deflection stiffness of the front and rear wheels [3]. Zhao Yilei1simplified steering as rotation around the main pin and derived the relationship between the rearward angle of the main pin and the steering stabilization speed using G. Komd's semi-empirical formula [4]. The model was fitted well in virtual experiments under specific track conditions. However, the model has limitations of its own, such as errors in the chosen semi-empirical formulation, which equates the car to a two-degree-of-freedom system and does not take into account the presence of camber lateral forces due to the camber of the car tyres, and the model also does not take into account the transfer of tyre loads. Therefore, some modification of the two-degree-of-freedom model for the tyres can better assist the simulation in deriving a more accurate equation for the relationship between the rear camber angle of the main pin and the steering steady vehicle speed.

For this two-degree-of-freedom model, a modified model has been proposed by establishing a set of equations for the balance of the lateral camber direction and introducing camber lateral forces for derivation, a modified two-degree-of-freedom model has been obtained: the axle load relationship during side leaning has been introduced and the camber lateral forces of the four wheels have been brought in. We propose to use this modified two-degree-of-freedom model to establish a more accurate equation for the relationship between the main pin camber angle and the steering stabilization speed. To determine the relationship between the main pin backlash angle and the maximum steering speed, we first establish the linear vehicle dynamics equations with two degrees of freedom for lateral and transverse oscillation around the centre of mass, simplifying the steering system as a rotation around the front wheel main pin, ignoring the frictional and viscous drag moments of the system, while the total front wheel drag distance is composed of the front wheel air tyre drag distance and the main pin backlash drag distance, and the front wheel main pin is approximated by the wheel centre as a complement to the steering system dynamics equations. The main pin of the front wheel is approximated by the wheel centre, and the steering system dynamics equation is used as a supplementary equation to the vehicle dynamics equation, and as a set of equations to obtain the characteristic equation by Rasch transformation [5].

$$\alpha=\arcsin\left(\frac{I_\delta(k_1a+k_2b)}{k_1mabR}\right)\left(2-\frac{k_2l\text{^}2}{mav\text{^}2}\right)-\frac{\zeta_1}{R} \tag{2}$$

Substituting in the various data from the vehicle, the equation can be plotted using python programming to obtain an image of the variation of the car's main pin rear camber versus the car's smooth steering limiting speed as follows [6]. Relationship between rear camber angle and vehicle speed as shown in Figure 1.

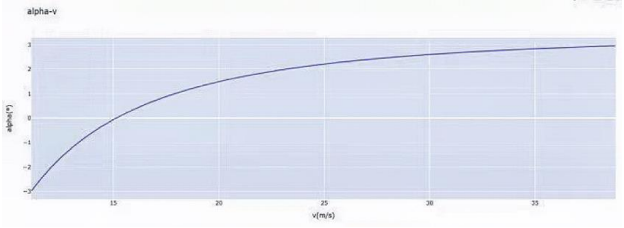
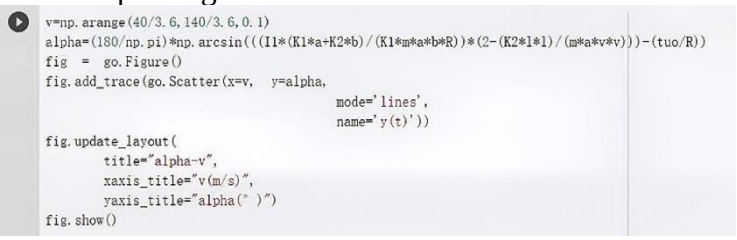


Figure 1. The relationship between rear camber and vehicle speed

From the above images it can be seen that the size of the rear camber angle of the main pin of the car and the speed are positively correlated, but when the speed is low, the angle increases faster, while when the speed value is higher, the change of the rear camber angle of the main pin also tends to flatten out.

Take the experimental data of this model as an example, the design value of the front main pin camber angle size is 2.0°±20', from the image to take points can be derived, when the speed is 27 m/s, i.e. 97.2 km/h, the camber angle value reaches the upper limit of the design value, so it can be judged that when the driving speed of the car is below 97.2 km/h, it is possible to ensure the steering The safety of driving is ensured[7].

Therefore, with this model, we can bring in the relevant values for different car models to determine the maximum steering stability speed of the vehicle under the design specification for the rear camber angle of the main pin. Figure 2 shows the code that needed to draw figure 1.



```
v=np.arange(40/3.6,140/3.6,0.1)
alpha=(180/np.pi)*np.arcsin(((I1*(K1*a+K2*b)/(K1*m*a*b*R))*(2-(K2*l*l)/(m*a*v*v)))-(tuo/R))
fig = go.Figure()
fig.add_trace(go.Scatter(x=v,  y=alpha,
                                    mode='lines',
                                    name='y(t)'))
fig.update_layout(
        title="alpha-v",
        xaxis_title="v(m/s)",
        yaxis_title="alpha(° )")
fig.show()
```

Figure 2. Code for Figure 1

Further research directions and limitations: In this problem, the size of the towing distance is a fixed value, but in actual operating conditions, the length of the towing distance is affected by whether the car is empty or fully loaded, the angle of steering, etc. In the future, experiments or simulations can be conducted to further determine the size of the towing distance under different operating conditions.

2.4. Application of ADAMS/CAR to build a complete vehicle simulation model

2.4.1. Selection of vehicle parameters

The vehicle parameters include geometric, mass, mechanical and external parameters.

When building the model in the ADAMS/CAR modelling interface, the hard point is determined to determine the position and orientation of the component. Finally, the model is completed by defining the parameter variables and the communicator for connecting the components between the templates.

2.4.2. Modelling the front suspension

The main advantage of a double wishbone independent suspension is the large degree of freedom in setting the front wheel alignment parameters and the position of the centre of roll. When modelling the suspension system in the ADAMS/CAR module, only the left-hand side of the suspension is modeled as the left and right parts of the model are automatically generated symmetrically. The front double wishbone independent suspension model is analyzed. It consists of: two upper and lower swing arms, two damper upper and lower piston rods, the body, left and right steering knuckles, a total of 9 rigid bodies and 2 elastomer. The upper and lower arms are connected to the body by ball hinges and steering knuckles; the upper piston rod of the damper is connected to the body and the lower piston rod to the lower arm by universal joints; and the upper and lower piston rods of the damper are connected by a cylindrical pair [8].

2.4.3. Rear suspension modelling

The rear suspension of the car is also a double wishbone independent suspension. As the rear suspension is similar to the front suspension, the structure and connections are basically the same.

2.4.4. Modelling the steering system

The steering system is the actuator of the vehicle. The mechanical steering system consists of three main parts: the steering mechanism, the steering gear and the steering transmission mechanism.

Depending on the steering mechanism, there are three types of steering gears: the recirculating ball - rack and pinion type, the recirculating ball crank and pinion type, the rack and pinion type and the worm gear crank and pinion type. A rack and pinion steering mechanism is used, which is input from one side and output in the middle. The steering system consists of a steering wheel, steering shaft, steering column tube, steering cross tie bar and steering rack and pinion. The steering wheel is connected to the upper end of the steering shaft by a fixed hinge, the upper steering shaft is connected to the body by a turning hinge, the upper, middle and lower sections of the steering shaft are connected to each other by universal joints, while the steering shaft is connected to the steering rack by a coupling hinge, the steering rack is connected to the body by a moving sub and can be moved from side to side relative to the body, and finally the steering cross tie rod is connected to the body by a universal joint and a ball The final connection is made by a universal joint and ball hinge, which connects one end of the steering cross-rod to the rack and the other end to the knuckle assembly[9].

2.4.5. Braking system modelling

The braking system model is obtained by modifying the parameters of the braking system template provided by ADAMS/CAR. The model uses an X-type hydraulic dual circuit braking system with disc brakes on both the front and rear wheels. The simplified braking system consists of calipers and discs.

2.4.6. Tyre model

The matching of the lateral deflection stiffness of the front and rear tyres directly determines whether the steady-state response of the car is under steer, neutral steer or over steer, which is an important factor affecting the car's handling stability. Therefore, the use of a suitable tyre model is an important indicator to ensure that the simulation results of the whole vehicle model are highly accurate and realistic to the actual situation. The ADAMS software provides four tyre models for dynamics simulation calculations, namely the default Fiala model, UA model, Smithers model, DELET model and, in addition, user-defined models[10].

The magic formula is a combination of trigonometric functions to fit the tyre test data to a set of formulas that expresses the longitudinal force Fx, the lateral force Fy, the return moment Mz, the flip moment Mx, the resistance moment My and the combined longitudinal and lateral forces of the tyre, hence the name "magic formula".

2.4.7. Driver's model

ADAMS/CAR provides three types of analysis: open-loop, closed-loop and quasi-static. The open-loop and quasi-static analyses require the user to input accurate and valid mass and structural parameters, while the closed-loop analysis is more complex and less easy to implement. Open-loop analysis can be used to give an input signal directly to the steering wheel; closed-loop analysis can be used to control the vehicle model for steady-state testing and to edit data such as steering, throttle, brake, gear and clutch to set the vehicle's driving state and trajectory, then transfer the data to the vehicle model for simulation and continue to gradually increase the vehicle speed for other simulation tests.

2.4.8. Body modelling

The body model is built by taking into account a certain air resistance factor, i.e. an air density of 1.23/ mkg and an air resistance factor of 0.36, throughout the simulation process[11]. As the body is an important part of the subsystems such as the suspension and braking system, special attention should be paid to the accuracy of the relationship between the body and the subsystems when building the body model. This will ensure the successful completion of the simulation analysis of the whole vehicle.

2.4.9. Subsystem creation

The main steps in creating a subsystem are as follows: determine the name of the subsystem, select the auxiliary parts (generally front for front suspension and front wheels, rear for rear suspension and

rear wheels, front for front drive line, any for others), select the corresponding template for the subsystem to be created and determine the distance the template is to be moved from its default position. After importing the template into the standard interface, you can modify the design data and property files of the template as required, and then save the subsystem.

2.4.10. Complete vehicle assembly

The subsystem models are assembled and connected in the standard interface of ADAMS/CAR to obtain the dynamics simulation model of the complete vehicle.

3. RESULTS

Handling stability is very important for the ease of handling and the safety of high-speed motoring. There are many indicators that can influence and evaluate handling stability. For example, steering sensitivity and reaction time can be used to evaluate the steady-state and transient response under the angular step input of the transition disc; resonance peak frequency, amplitude ratio at resonance, phase lag angle, etc. can be used to evaluate the transverse swing speed frequency response characteristics; steering sensitivity and steering disc force characteristics can be used to evaluate the steering stability in the middle position of the steering disc; residual transverse swing speed and residual swing angle can be used to evaluate the return to squareness after the return to squareness; minimum steering radius can be evaluated; steering force and steering power can be evaluated; steering wheel angle and lateral deflection can be evaluated for straight-line driving performance and lateral wind sensitivity, road surface unevenness sensitivity; steering wheel angle, steering force, lateral acceleration and angular velocity can be evaluated for some typical driving conditions (serpentine performance, shifting linear performance, double shifting linear performance); ultimate lateral acceleration and ultimate The ultimate lateral acceleration and ultimate speed can be used to evaluate the ultimate driving capability (rollover resistance, ultimate lateral acceleration for circular driving). Through simulation and python modelling of the various relationship curves, it is possible to know that in the design and development process of the vehicle, the height of the centre of mass should be reduced as much as possible, the mass of the vehicle should be reduced, the lateral deflection stiffness of the tyres should be improved and the camber of the front wheels should be increased appropriately, an agile and accurate steering wheel, a solid and resilient suspension system, an engine with a large torque range, a streamlined exterior design, an anti-skid control system ABS so that the handling stability of the vehicle can be improved. Improved handling stability throughout the vehicle.

4. CONCLUSION

The main research content and conclusions of this paper can be summarized as follows.

Taking the rear camber of the main pin as an example, with the help of python and two degrees of freedom model, a system of equations is listed and the relationship is solved to derive the relationship between handling stability and the camber of the main pin, vehicle speed, vehicle distance, etc. However, the two degrees of freedom model also has certain limitations, the two degrees of freedom model ignores the role of the suspension, the whole vehicle is simplified to two wheels, the lateral deflection characteristics of the tyre is considered linear, and the longitudinal drive or drag is ignored, and the longitudinal The speed of the car remains unchanged and the existence of errors in the empirical formulae inevitably affects the accuracy of the calculation; the role of the suspension is neglected and the carriage is considered to be moving only in a plane parallel to the ground, i.e. the displacement of the car along the z-axis, the pitch angle around the y-axis and the lateral inclination angle of the railing x-axis are all zero; the lateral acceleration is limited to less than 0.4g to ensure that the tyre lateral deflection characteristics are within the linear range; the influence of air resistance is neglected; the car is The car is simplified to a model with only two degrees of freedom, lateral and

transverse, so that the origin of the vehicle coordinate system coincides with the centre of mass of the car. And there will be some deviation from the theoretical calculation in real life

As the handling stability of the vehicle is closely related to the driver's handling characteristics, closed-loop simulation validation considering the driver's control information is closer to the actual vehicle driving conditions, thus providing a more realistic, accurate and efficient simulation study. A multi-body dynamics model of the whole vehicle is established, including seven sub-systems, including the front suspension sub-system, steering system, body sub-system, rear suspension sub-system, tyre sub-system, braking system and power system; a constant turning radius test and snaking test are carried out using the real vehicle of the school fleet. The test data and the simulation data have the same trend of change and the error is small, which can verify the accuracy of the proposed multi-body dynamics model.

During the design and development of the vehicle, the height of the centre of mass should be reduced as far as possible, the mass of the vehicle should be reduced, the lateral deflection stiffness of the tyres should be improved and the camber of the front wheels should be increased. To obtain a better and more comprehensive vehicle handling stability performance, other parameters need to be considered for optimization and matching.

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