The Relationship between Car Caster Angle and the Directional Stability of Car

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Abstract. Appropriate alignment parameters may maintain stability of driving and handiness of operation, and automatic returnability of the steering system when the vehicle goes on straight. The alignment parameters of wheel and the steering mechanism are very important factors on tire wear. Among these parameters, the caster angle of the car is one of the most important factors to maintain the stability of the car. Choosing a suitable caster angle will reduce the wear degree of the car and improve the safety factor. Decades of research into the relationship between vehicle stability and caster angle have been exhaustive. From a large number of experiments in the past to the development of modeling software in recent years, people can use modeling software to simulate and obtain more accurate results. It will focus on the analysis methods using several typical modeling software on the market, and finally obtain the quantitative and qualitative relationship between the vehicle directional stability and caster angle.

Keywords: Alignment parameters, Steering mechanism, Simulation, Caster angle, Stability.

1. INTRODUCTION AND BACKGROUND

It believes that whether a car floats at high speed depends mainly on two parameters: the caster and steering wheel sensitivity. These two parameters are sufficient for many people to experience the stability of a car running at high speed [1]. In car dynamics, stability is essential to the safety of the driver. While pursuing higher speed, safety cannot be ignored. Among these parameters, the caster angle of the car is one of the most important factors to maintain the stability of the car.

The front shock absorber of the car is not completely perpendicular to the ground, and most of it is inclined backward, and the angle of the rearward inclination of the shock absorber is called the caster [2]. Caster angle is the angle between the king pin and the suspension system viewed from the side of the car, locomotive, or bicycle body. Generally, a negative caster angle represents better flexibility, and a positive caster angle has a more stable straight forward. In short, the caster angle can be regarded as the angle between the wheel axis and the vertical line of the ground. Racers often adjust the caster angle to optimize the handling of the car in certain driving situations.

The caster angle can be defined as the side view inclination of the steering axis. Generally, the range of caster angle is 0 to 6 degrees. This introduces a mechanical trial called caster trial which in conjunction with pneumatic trial is very important in giving a steering a suitable feel and also has a significant effect on directional stability because of steering compliance. The steering feel is adjusted to obtain desired relationship between lateral force and aligning torque [3].

The main function of the caster angle is to keep the vehicle driving straight ahead. If the caster angle is positive, when the front wheels are turned, the inside of the vehicle will drop down, and the chassis will rise as a result. As a result, the load is added to the steering knuckle, and if the caster angle of both wheels is the same, the vehicle will return to the front after turning. Increasing the positive caster angle can increase the stability of the steering wheel, but the force will increase when turning; Decreasing the positive caster angle reduces the stability of the steering wheel, but it turns with less force. The angle of the caster angle does not affect tire wear, it is used to stabilize the direction of the vehicle and automatically return to alignment when turning. If the vehicle is equipped with a traditional manual steering wheel, the caster angle is small or even tends to be negative, which can make steering easy. If the vehicle is equipped with a power steering wheel, the caster angle is

usually set to a larger positive caster angle, which makes the driver feel more steering. Increasing the positive caster angle will increase the steering force, but it can increase the stability of the vehicle straight.

Adding caster trial moves the point of maximum steering torque closer to the point of maximum lateral force, or even beyond it that is steering goes lighter. During cornering the steering must also support the centrifugal compensation forces on the steering mechanism. This is called centrifugal caster [4].

In the 19th century, when the concept of a locomotive was first introduced, there was little awareness of how to improve stability and reduce skidding. In May 1896, Arthur Constantin Krebs was the first to apply positive recoiling Angle to his locomotive. The purpose of the design is to provide an Angle at which the turn can be reversed naturally.

Therefore, based on the introduction of the camber angle in the first part, it will focus on the second part to introduce the formula for measuring the camber angle and the method of modeling using the ADAMS software. In the third part, the difference of the camber angle measurement of the two different structures is introduced, and the corresponding conclusions are drawn at last.

2. RESEARCH METHOD

2.1. Formula Derivation

Since predecessors have deduced the expression for matching the caster angle of the front wheel kingpin with the stable limit vehicle speed, the mathematical model of the back-righting torque and the back-righting resistance torque around the kingpin after the front wheel is steered has been established, and the value of the inclination angle provides a theoretical reference for the improved design of the caster angle of the main pin, but these are all quantitative analysis of the main pin from a linear perspective [5].

The relationship between inclination angle and stable limit speed. And it intends to discuss the relationship between the caster angle of the kingpin and the stable steering angle of the vehicle by using the nonlinear numerical analysis method.

$$mu(\dot{\beta}+\gamma)+m_s h\ddot{\varphi}=F_1+F_2+F_3+F_4 \tag{1}$$

$$I_{ZZ}\dot{\gamma}=a(F_1+F_2)-b(F_3+F_4)+M \tag{2}$$

$$I_{XX}\ddot{\varphi}+C_{\varphi}\dot{\varphi}+K_{\varphi}\varphi=-m_s u(\dot{\beta}+\gamma)h+m_s g\varphi h \tag{3}$$

$$M=F_y r sin\phi \tag{4}$$

β: Vehicle center of mass slip angle.
γ: Angular velocity of vehicle yaw.
φ:Centroid roll angle.
m: The mass of vehicle.
m_s: The mass of vehicle suspension.
$F_1F_2F_3F_4$: Side force.
a, b: the centroid's Distance from front and rear axles.
I_{ZZ}, I_{XX}: Moment of inertia.
C_{φ}, K_{φ}: Roll damping.
u: Longitudinal velocity.
M: Kingpin backward tilt back positive moment.
r: The radius of tire.
ϕ: Kingpin caster angle.

2.2. ADAMS Software

When studying various performances of automobiles, the modeling, analysis and solution of the research object are always the key. The multibody system dynamics software ADAMS provides powerful mathematical analysis tools for vehicle dynamics research.

The ADAMS software developed by Mechanical Dynamics is the most widely marketed mechanical system simulation software in the world. The so-called MSS technology is to combine the scattered parts design and analysis technology to provide a comprehensive understanding of the working performance of the product, and to guide the design through the feedback information in the analysis [6].

Using the ADAMS software, a standard model is imported and with the view to study the effect of caster angle, all the components of suspension system such as mounting point, track width, wheelbase, mass were modified and incorporated into new model to meet the requirements [7].

With the rapid development of computer technology, the theoretical methods and calculation methods of multi-rigid-body system dynamics have made a qualitative leap, and the application of multi-rigid-body system dynamics in the field of automotive technology has gradually expanded. In foreign countries, the research of vehicle dynamics has gone through a process from experimental research to theoretical research. The mechanical model is also developed from a linear system model to a nonlinear system model, and the number of degrees of freedom of the model that can be processed has also developed from a few to hundreds. The mid-1980s was the period when the application of multi-rigid-body system dynamics in the automotive field was the fastest. Major foreign automobile manufacturers and research institutions have used multi-body system dynamics software in their automobile design and development systems, and together with software such as finite element, modal analysis, and design optimization, they form an organic whole [8].

Using the interface of ADAMS software and ANSYS software, the application of finite element analysis to the components with large elastic deformation such as the tie rod of automobile steering mechanism is carried out in-depth research. Determine the design variables of different groups, examine different objective functions, give full play to the computer's ability of high-speed operation and logical judgment, carry out a large number of optimization analysis, and obtain the optimal results, which provide a reliable theoretical basis for the actual design.

ADAMS software is based on multi-body dynamics theory for kinematics, statics, and dynamics analysis, and is the product of a high degree of integration of multi-body system dynamics theory and computer [9]. The application of ADAMS software to simulate and analyze a typical mechanical system can be divided into the following six steps:

(1) Abstraction of mechanical system under large displacement conditions; (2) Modeling by abstracting the components, hinges, and forces of the system; (3) describe the parameters of components, hinges and forces on the computer; (4) Establish system kinematic equations; (5) Solve the kinematic equation of the system; (6) Graph and animate the equation solution.

This topic will introduce a part of the application of the mechanical dynamics analysis software ADAMS to analyze the vehicle positioning parameters and steering mechanism. ADAMS software is a calculation program compiled by American scholar Chase and others using the theory of multi-rigid body dynamics to select the three rectangular coordinates of the center of mass of each rigid body in the system in the inertial reference frame and the generalized coordinates that reflect the orientation of the rigid body. Among them, the algorithm of Gill et al. to solve the rigid integral problem is applied, and the sparse matrix technique is used to improve the computational efficiency. The software has been widely used in the fields of automobile and aerospace due to its powerful functions.

2.3. Relevant Principles

There is a direct geometric relationship between the two groups of camber angles of the sensor and the angle of the king pin due to the structure. For the double swing arm suspension structure, the tire is connected to the body through the steering knuckle and the ball joint swing arm, and the axis

of the king pin is reflected as the connection between the upper and lower ball joints; For the McPherson suspension structure, the tire is connected to the body through the steering knuckle, the lower ball joint swing arm and the slid, and the axis of the king pin is reflected as the connection between the lower ball joint and the center of the upper bearing plate. In fact, the upper and lower joints of the steering knuckle represent the axis of the kingpin, which is in a constant orientation and can be understood as a rigid body. The left and right rotation of the front wheel is the rotation of the tire around the connection line between the upper and lower points of the steering knuckle, that is, the tire rotates around the axis of the king pin through the steering knuckle. Suppose that the wheels are placed on a turntable that can freely rotate left and right. In the case of simply considering the caster angle of the kingpin (set the inclination angle to be zero), the tire will rotate left and right around the slant line determined by the caster angle. From this, the following geometric model is established in principle. As the tire rotates left and right on the turntable, the center plane of the tire rotates around an oblique line representing the caster angle, and the camber angle of the tire changes accordingly.

During the driving process of the vehicle, the front wheel often vibrates. Under the extreme working conditions, the stable wheel angle range is much smaller than the general working condition. Although the amplitude of the sway vibration is small, the existence of the sway vibration may still lead to the instability of the vehicle under extreme working conditions.

3. DISPLAY OF RESULTS

3.1. Candle Suspension-Integral Steering Mechanism Model

By using the constraint library provided by the software and the meticulous research on the related mechanism of the vehicle, this subject establishes a suspension-steering mechanism simulation model to study the tire wear problem. The model basically includes the degrees of freedom required for kinematic analysis.

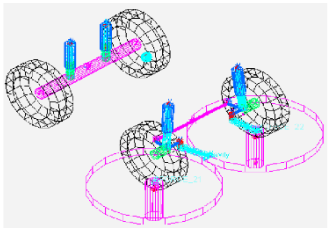


Figure 1. Candle Suspension-Integral Steering Mechanism Model

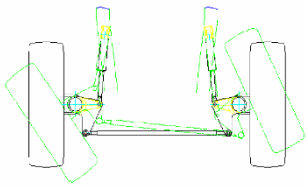


Figure 2. The CAD image of car

Figure 1 and 2 give us a simplified model. The simplified model includes steering knuckles (two), steering wheels (four), suspension (four), steering trapezoidal arms (two), steering tie rod, axle, chassis and so on [10]. In the model, the steering knuckle and front suspension are constrained by rotation pairs. Suspension is composed of two parts (cylinder and push rod), the use of mobile pair connection, suspension part (cylinder) and the vehicle centroid with fixed pair connection; The suspension part is installed with a spring, when the suspension push rod moves up and down, the spring is telescopic, and the stiffness and damping coefficient of the spring are the parameters of the original car suspension; The rear suspension is connected with the rear axle using a fixed pair, and the rest of the connection is similar to the front suspension; Because it is a full hydraulic steering system, the steering hydraulic cylinder is replaced by a spring in the model. The front end of the

spring is connected with the frame with a fixed pair, and the rear end of the spring is connected with the steering arm with a rotating pair. The steering trapezoidal arm is connected with the steering joint by a rotating pair; The steering trapezoidal arm and the steering tie rod are connected with a universal joint pair; The test bench is connected to a flat tire pair [11].

3.2. Simulation Analysis of the Model

3.2.1. Changes of positioning parameters under different driving conditions

In Figure 3, the interaction between vehicle positioning parameters under different driving states is studied. The simulation process is that the car runs at different speeds from the static state, and the simulation time is 8 seconds. The driving state includes :(1) the vehicle travels at a uniform speed with a speed of 8m/s, and the center of mass and the ground are constrained by moving deputy; (2) The vehicle travels at a uniform speed, at a speed of 12m/s, and the center of mass and the ground are constrained by moving deputy; (3) The acceleration of the vehicle is 1.6m/s^2, and the center of mass and the ground are constrained by moving pairs; (4) The vehicle accelerates, with an acceleration of 1.6m/s^2, and there is no constraint between the center of mass and the ground.

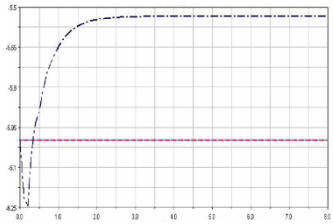


Figure 3. Changes in caster angle of the kingpin

It can be seen that during the driving process of the car, if the position of the center of mass of the car does not change, the positioning parameters will not change, but if the position of the center of mass of the car changes, the positioning parameters will change. Therefore, the following mainly studies the change of the positioning parameters when the car mass center is unconstrained.

3.2.2. Changes in positioning parameters when changing vehicle structural parameters

In Figure 4, we mainly study the effect of changing the vehicle structure parameters on the localization parameters. The simulation content is as follows:(1) Initial set acceleration of the car: acceleration 1.625m/s^2 (maximum vehicle speed 47 km/h) (2) Decrease acceleration: acceleration 1.15m/s^2 (maximum vehicle speed 35 km/h)(3) Change the stiffness of the front suspension (644N/mm down to 444N/mm)(4) Change front suspension damping (300 N-s/mm up to 500 N-s/mm)(5) Change the rear suspension stiffness (2176 N/mm down to 1176 N/mm)(6) Change the rear suspension damping (250 N-s/mm to 500 N-s/mm).

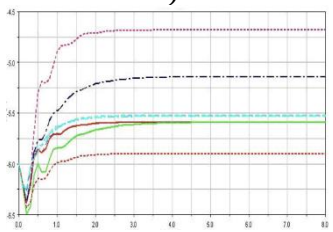


Figure 4. Changes in positioning parameters when changing vehicle structural parameters

The first line is the change curve of the caster angle when the vehicle is under heavy load; The second line is the change curve of front suspension stiffness and caster angle change; The third line is the change curve of the caster angle when the acceleration is reduced; The fourth line is the change curve of the rear suspension stiffness and the rear inclination angle; Change the other parameters, the curves basically coincide.

Based on the fourth line, compare and change the trend of the dip Angle of each parameter. As can be seen from the fourth line, when the vehicle acceleration driving, the Angle of the Angle is stable at 5.6°, the actual value of the Angle is smaller than the theoretical value. By comparing the

first and fourth lines, it can be seen that the vehicle load has a great influence on the caster Angle. As the load increases, the stable value of the caster Angle decreases, which is stable at 4.7°. In other words, the actual value of the caster Angle will decrease again as the load increases. By comparing the second and fourth lines, it can be seen that the front suspension stiffness has a great influence on the caster Angle. When the front suspension stiffness is reduced, the stable value of the caster Angle decreases again, and the value is stable at 5.1°. By comparing the third and fourth lines, it can be seen that when the acceleration is reduced, the stable value of the caster Angle decreases again and is stable at 5.5°. By comparing the bottom curve with the fourth line, it can be seen that when the stiffness of the rear suspension is reduced, the stable value of the caster Angle increases, which is stable at 5.9°. In addition, the reaction time of the system increases with the increase of front suspension damping. Therefore, the influence of acceleration, load, front suspension stiffness and rear suspension stiffness on the actual stability value of the caster Angle should be considered when designing the caster Angle, and the final design value should be further increased.

4. CONCLUSION

When the car accelerates, the caster angle decreases. If the setting value of camber Angle is reduced, the stable value of caster Angle will continue to weaken, and other parameters have little influence on the change of caster Angle. The caster Angle is stable at 5.6°. The caster Angle is almost constant during steering. In the case of heavy load, the caster Angle increases gradually with the increase of wheel Angle.

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