Caster Angle and Directional Stability of a Car Application to Sports Car

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Abstract. Caster Angle is the Angle between the kingpin and the suspension system, as seen from the side of a car, locomotive, or bicycle. The front wheel often vibrates when the vehicle is running. When the caster Angle of the front wheel kingpin becomes larger, the shimmy will occur simultaneously, which will increase the possibility of vehicle instability. Appropriate alignment parameters may maintain stability of driving and handiness of operation, and automatic returnability of the steering system when 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. Therefore, the topic of this study is the relationship between vehicle rearward Angle and vehicle driving stability. This study adopts Carsim modeling. It is concluded that as the caster angle increases, the car becomes more unstable when it is steered and less stable. While as the caster angle increases, the stability of the car increases when driving in a straight line.

Keywords: Caster angle, Stability, Python, Roll angle.

1. INTRODUCTION

The handling stability of the car refers to the ability of the car to resist the interference and maintain a stable driving when the driver does not feel excessive tension and fatigue, and the car can resist the interference and maintain a stable driving when it encounters external interference [1].

car handling stability is an important indicator affecting the driving performance of the car, determining the safety performance of the car when driving at high speed, with the continuous development of the level of science and technology, and the construction of modern roads Today's cars can reach a speed of 80km/h on ordinary highways, and on the highway can reach a speed of 200km/h, so the stability of vehicle handling has become particularly important. Vehicle handling stability is also known as the "lifeline of high-speed vehicles"

Whether the front wheel positioning of the vehicle is correct or not is the key condition to ensure whether the vehicle has good handling stability, safety, fuel economy, etc. The positioning parameters of the front wheel change with the wheel runout and the longitudinal and lateral forces of the wheels being subjected to When the vehicle is driving at high speed in the cornering direction, the stable limit speed is related to many factors, such as the position of the center of mass of the vehicle, the moment of inertia of the steering system, the total towing distance of the tire and so on. The total tire tow distance is composed of the tire tow distance and the main pin backward towing distance [2].

Previous studies have shown that when the car is driven in high-speed corners, its stability is related to many factors such as the moment of inertia of the car and the total tow distance of the tire. Among them, the total towing distance of the tire is composed of the trolley tow distance and the backlash of the main pin, which is the main factor affecting the stability of the car at high speed. Therefore, it is necessary to design a suitable front wheel mains backcamp angle to meet the needs of the vehicle's high-speed driving stability [3].

It is believed 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. 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. Therefore, the research content selected in this paper is the influence of caster angle on driving stability of automobiles.

The caster angle refers to the angle between the kingpin and the vertical line of the ground when viewed from the side of the body.

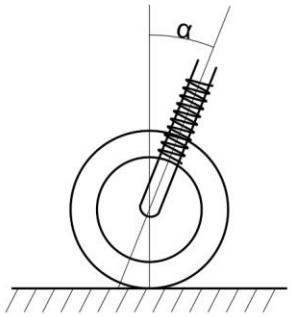


Figure 1. Cster angle

Figure 1 is a side view of the car wheel. The angle α in the figure is the caster angle of the car.

Kingpin caster angle is mainly designed according to the purpose of automatic steering, and inclination angle, its positive role is related to the speed, especially in the state of high-speed vehicle driving, caster angle plays a key role in the timing of the car cycle. When the vehicle has a kingpin caster angle, the wheel will be subjected to a lateral force applied by the ground, which will generate a positive moment and automatically return the front wheel of the vehicle. When the kingpin caster angle is smaller, the lighter the steering, the easier the wheels are to swing, and the larger the kingpin caster angle, the more difficult the vehicle is to steer.

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. 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. Simply put, the caster angle can be seen 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. 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. In the early 20th century, the German Chatterling prioritized the case of automatic return after front wheel steering and concluded that the kingpin caster angle was preferably 15deg. Setting the kingpin caster angle to this angle is a good way to guarantee the speed at which the front wheel automatically returns to normal after the turn is complete. But at the same time, the larger kingpin caster angle will have some negative effects. Not only will the turning process be laborious and impossible to turn quickly. It also leads to shimmy, which reduces the smoothness of the car's driving and handling stability. By 1950, the use of low-pressure tires improved the wheel's ability to straighten out, resulting in a general reduction in the kingpin caster angle reducing shimmy and wheel wear. The low pressure tyre has good elasticity and has a larger contact area with the road than previous tires. The tire pressure is low, the heat expansion is small, and the stability and safety are improved.

The control stability of ordinary cars has been studied in previous studies. In the previous study, the calculation formula of the caster angle of the front wheel kingpin was derived, and the calculation method of the caster angle of the kingpin of the front suspension of the car was established [4,5]. And also have shown that for ordinary cars, the front wheel main sales caster angle is generally between 5-10deg [6]. For example, the kingpin caster angle value of some vehicles: FAW Audi 100 is 1. 16°, EQ1091 is 2°30′, CA1091 is 1°30′ [7]. But there are relatively few studies on the control stability of sports cars and racing cars, and sports cars and racing cars can achieve higher speeds than ordinary cars, so the requirements for the control stability of such cars are higher.

In 2004, Professor Daogao Wei of Hefei University of Technology pointed out in a study that the wear status of the front wheel and the positioning parameters of the front wheel are important parameters that affect the driving stability of the car. The front wheel positioning parameters are currently determined mainly by empirical methods.

In 2002, Skip Essma used Adams to study the steering force of the car when driving on an elliptical track, analyzed the effect of changes in the inclination angle and the caster angle on the steering back positive torque, and found that the reduction of the inclination angle and the kingpin caster angle would lead to a decrease in steering ability, and the kingpin caster The reduction of the angle causes the front wheel to oscillate.

In 2006, LiQiang Jin et al. of Jilin University established a mathematical model of tire positive torque and steering resistance torque, and based on the outstanding mathematical model the relationship between the positioning parameters of the front wheel and the steering wheel control torque were obtained, and the kingpin caster angle and inclination angle were optimized according to the steering lightness.

In 2007, Daogao Wei,Keqiang Li, Xiaofeng Wang derived the matching expression between the kingpin caster angle and the limit stable speed, established a mathematical model of the positive moment and the positive resistance of the front wheel steering around the kingpin, and can calculate the value of the caster angle , providing an important reference for the improved design of the backward inclination angle, on the basis of this research, Wei Hu Daogao Wei, Peng Wang used a polynomial tire model in his 2012 study, established a vehicle steering driving that considers the body roll movement of three degrees of freedom, and used nonlinear numerical values to explore the influence of caster angle on the stability of steering and straight driving under extreme operating conditions.

In 2010, Associate Professor RunQi Wang of Central South University of Forestry and Technology derived the automatic back positive torque calculation formula including the front wheel positioning parameters, and pointed out that the caster angle and the inclination angle are important factors affecting the positive torque of the car's steering cycle. But there is no effect of wheel center pin offset on the result.

The reference [9] studied the effect of matching between the front wheel toe-in angle and the inclination angle on the wear condition of the tire. The front wheel inclination angle causes the vehicle to generate a lateral force, which causes the tire to slide during driving, and as the inclination angle increases, the more serious the skidding, the more serious the wear on the tire. The wheel toe-in angle can reduce this lateral force and reduce wear. However, setting the value of toe-in angle incorrectly will also cause the car to generate lateral forces during driving.

In 2009, Y. G. Cho studied the position relationship between the kingpin axis and the wheel, and analyzed the force on the tire under low-speed steering conditions. The positive moment generated by each side upward is calculated.

Steve Goddard and Paul Elwood of Dana company studied the effect of the kingpin offset distance of the front wheel on the maneuverability of SUV and light trucks. The results of the study show that a small front wheel kingpin offset distance, or a negative front wheel kingpin offset distance, can effectively improve the balance and stability of the vehicle when braking when the kingpin offset distance is too large, it is easy to cause the car to steer when braking, reducing balance and stability.

In this paper, the handling stability of the car is mainly studied in straight lines and curves, and this study uses carsim simulation to study. Many previous studies have used matlab programming to solve the data of the car when driving, compared with the simulation with carsim, the editing of various parameters of the car is more convenient and visual. Road data is also relatively rich, there are a variety of test environments. This paper uses double lane change and accelerate then brake (0-100-0kmph) to comprehensively study the relationship between the stability of cars in various driving conditions and the caster angle.

Table 1. The basic content of the vehicle's handling stability and the physical parameters used for evaluation

Project	Basic content	The main evaluation parameters
Straight line driving performance	Linear drivability Lateral wind sensitivity Road surface unevenness sensitivity Lane keep on uneven roads	Speed,Lateral offset , Centroid lateral declination angle,steering wheel angle
Cornering driving characteristics（Steady-state）	Portability of turning in place Portability of low-speed driving steering Portability of high-speed driving steering Steady-state circular driving Steering radius	Steering force, Steering power,Roll angle , Lateral declination angle, Lateral acceleration, Minimum turning radius
Typical driving conditions	Snake-shaped driving performance Lane change performance Obstacle avoidance performance	swing angle speed, Steering force,Speed, Lateral acceleration, Lateral declination angle

Reference [1] shows the above table to measure the stability of the car under different conditions.

Table 1 shows the basic content of the vehicle's handling stability and the physical parameters used for evaluation [2]. This paper mainly studies the stability of cars when driving in a straight line and turning (steady state). According to the data of Table 1, this paper uses roll angle as the evaluation index of the stability of turning driving (steady state); the steering wheel angle was used as the evaluation index of the stability of the car in a straight line driving.

2. Research Method

2.1. Automotive mechanics model

The system of differential equations for automotive mechanics at linear two degrees of freedom has been given [1,8].

The differential equation for the motion of a car with two degrees of freedom is

$$\left.\begin{aligned}(k_1+k_2)\ \beta+\frac{1}{u}(ak_1-bk_2)\omega_r-k_1\delta=m(\dot{v}+u\omega_r)\\(ak_1-bk_2)\beta+\frac{1}{u}(a^2k_1-b^2k_2)\omega_r-ak_1\delta=I_Z\dot{\omega}_r\end{aligned}\right\} \tag{1}$$

Since the pitch angle and roll angle are zero in the two-degree-of-freedom car motion model, it is necessary to add a three-degree-of-freedom automotive motion equation to this study. The corresponding equation of motion was given by reference [10]and reference [11], which is expressed as

$$\begin{aligned}&mu(\dot{\beta}+\gamma)+m_s h\ddot{\phi}=F_1+F_2+F_3+F_4,\\&I_{zz}\dot{\gamma}=a(F_1+F_2)-b(F_3+F_4)+M,\\&I_{xx}\ddot{\phi}+C\dot{\phi}+K_\phi\phi=-m_s u(\dot{\beta}+\gamma)h+m_s g\phi h\end{aligned} \tag{2}$$

β : sideslip angle of vehicle
γ : yaw velocity
ϕ : Centroid roll angle
m : The mass of vehicle
m_s : The mass of vehicle suspension
a, b : Distance from the center of mass to the front and rear axles
F_1, F_2, F_3, F_4 : Side force of the tire
$I_{zz,} I_{xx}$: Moment of inertia
C_ϕ, K_ϕ : Roll damping
u : Longitudinal velocity
M : Kingpin backward tilt back positive moment
ϕ : Kingpin caster angle

2.2. Carsim Simulation

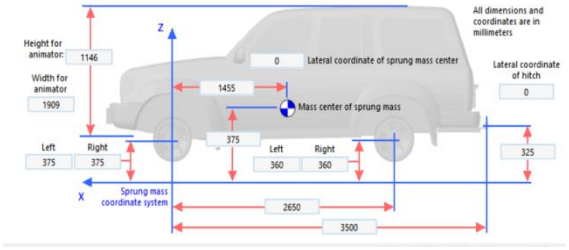


Figure 2. Parameters of car model

Figure 2 shows the parameters of the model uesd in this research .

In order to study the control stability of straight-line driving and turning driving, the road data used in the simulation were double lane change (120km/h) and accelerate then brake (0-100-0km/h) respectively.

3. Simulation experiment data

3.1. Cornering driving simulation

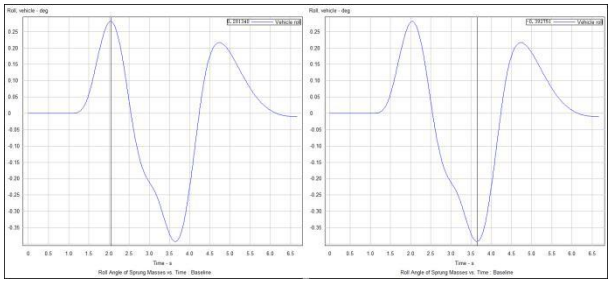


Figure 3. Roll angle of sprung masses（caster angle=0°）

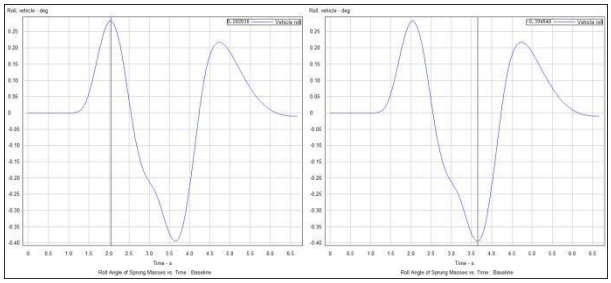


Figure 4. Roll angle of sprung masses（caster angle=3. 5°）

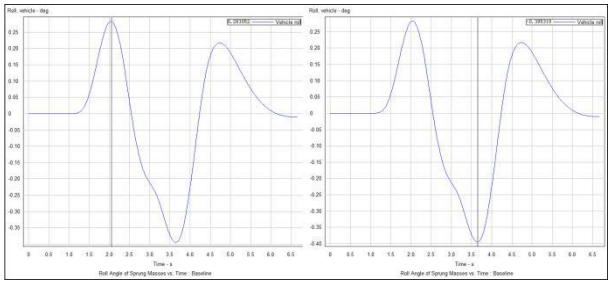


Figure 5. Roll angle of sprung masses（caster angle=5°）

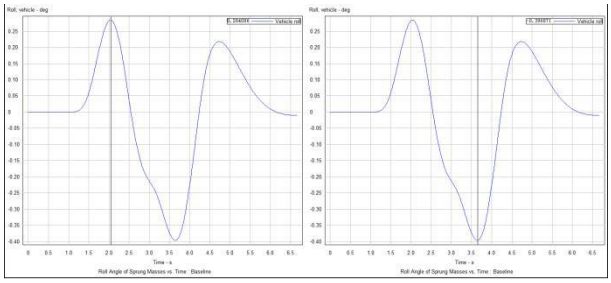


Figure 6. Roll angle of sprung masses（caster angle=8°）

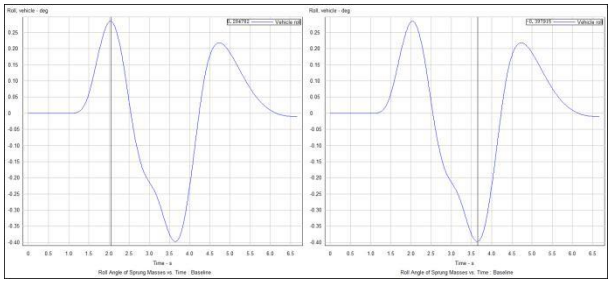


Figure 7. Roll angle of sprung masses（caster angle=10°）

Figure3 to figure7 shows when the front wheels have different caster angles, the roll angle of the spring mass changes over time, and the peak of the roll angle is marked in the figure.

Plot the maximum of the absolute value of the roll at the time of a turn corresponding to each set of different caster angles in the same plot

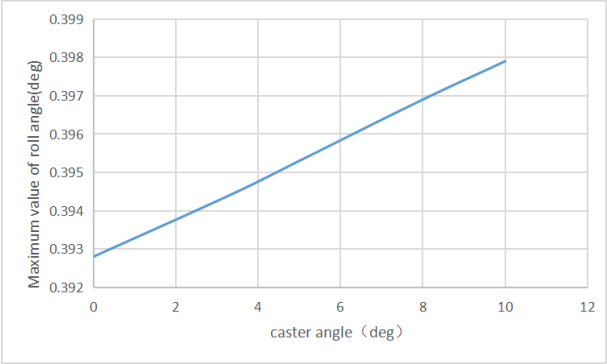


Figure 8. maximum value of roll angle over caster angle

From figurine8, it can be seen that the roll angle increases as the caster angle increases, which means that the stability of the car decreases as the caster angle of the front wheel increases when the car makes a double lane change.

3.2. Straight line driving simulation

In order to better simulate the state of the car in a straight line in reality, this study uses the process of accelerating from 0kmph to 100kmph, and finally decelerating, which includes the three states of car acceleration, uniform speed and deceleration, which is more realistic

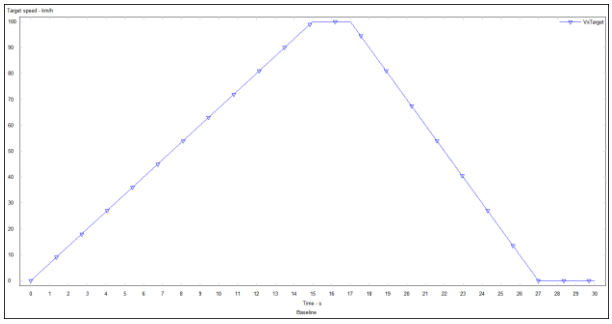


Figure 9. Speed of the car

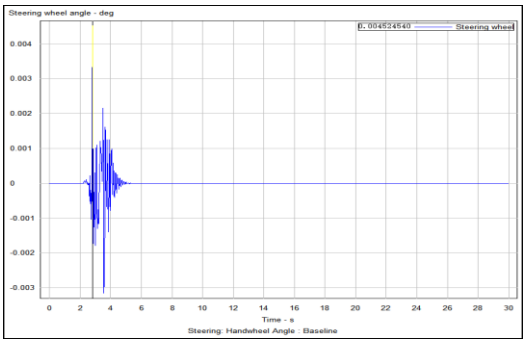


Figure 10. Steering wheel angle(caster angle=0°)

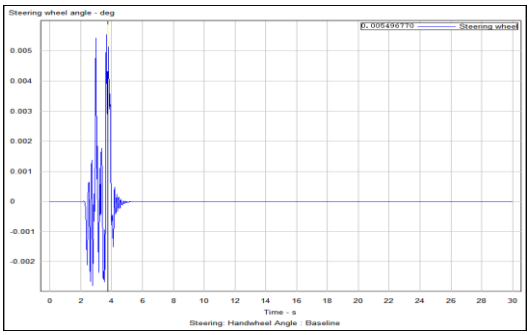


Figure 11. Steering wheel angle(caster angle=3. 5°)

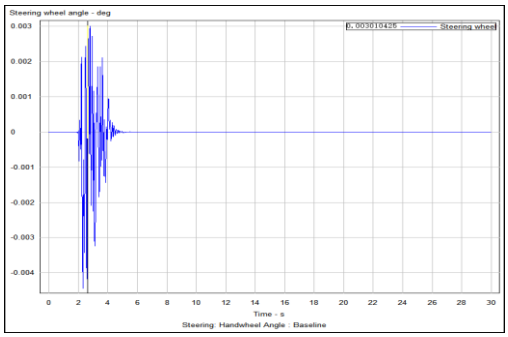


Figure 12. Steering wheel angle(caster angle=5°)

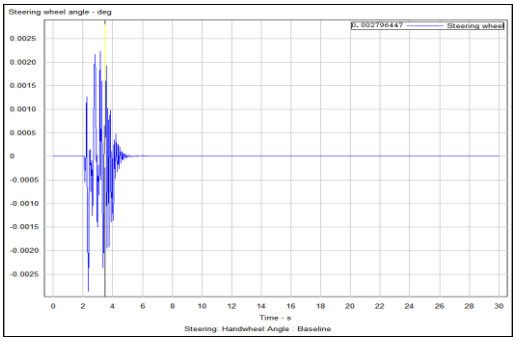


Figure 13. Steering wheel angle(caster angle=8°)

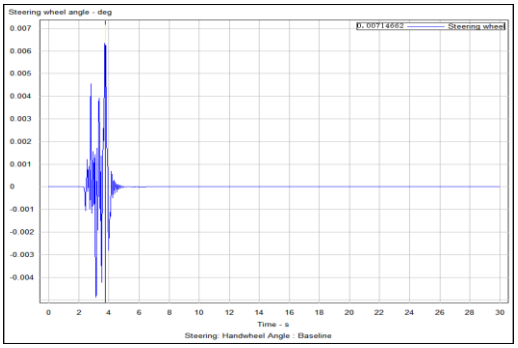


Figure 14. Steering wheel angle(caster angle=10°)

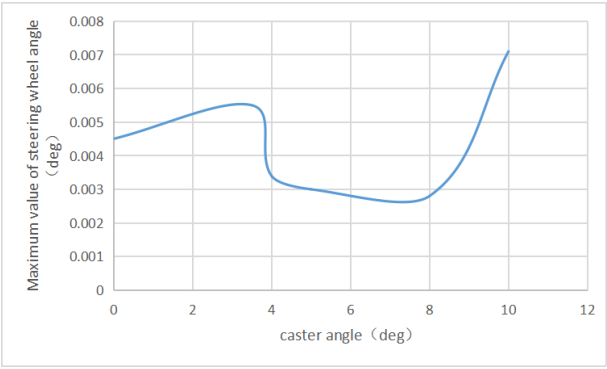


Figure 15. Maximum value of steering wheel angle over caster angle

From figure 14, it can be seen that with the increase of the caster angle Maximum value of steering wheel angle first increases slightly, and then decreases slightly, when the caster angle is greater than 8deg, maximum value of steering wheel angle increases rapidly with the increase of the caster angle.

4. Conclusion

With the change of the car's caster angle, it can be seen that the peak of the roll angle of the car's steering driving continues to increase, and the stability decreases; when the car is driving in a straight line, the peak of the steering wheel angle changes with the law of the more complicated. As can be seen from the figure, when the caster angle is from 4deg to 8deg, the car's steering wheel angle is small, and it slowly decreases with the increase of the caster angle. According to the above conclusion, due to the small stability improvement in the 4deg to 8deg range when driving in a straight line, and the stability of the roll angle during turning driving is basically linear, the maximum value of steering wheel angle continues to increase as the number of kingpin caster angles increases. In order to meet the stability of the car in both straight line driving and turning, the caster angle of the car is better to selected in the 1deg to 4deg range.

This paper only examines the relationship between vehicle handling stability and kingpin caster angles. In the actual car driving process, there are many factors that affect the stability of car operation, such as parameters such as inclination angle and toe angle, and the impact of other vehicle parameters on driving can be continued in the future, and the impact of multiple parameters on the control stability can also be considered comprehensively.

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