Simulation Study on the Influence of Suspension Rigidity on the Controllability and Stability of Baja Racing Car

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Abstract: In this paper, a complete vehicle model of the Baja racing car is established through Adams/car. Through the establishment of virtual simulation experiments, three typical working conditions of steering wheel step input, steering wheel pulse input and single-line shift are tested respectively; by comparing each of the racing cars State parameters are used to evaluate the handling stability of Baja racing cars with different suspension spring stiffnesses, and then to study the influence of suspension spring stiffness on the handling stability of the car. The test results show that increasing the stiffness of the suspension spring reduces the car's lateral acceleration, yaw rate, and roll angle amplitude, which improves the steering stability of the car. Therefore, it can be considered that a reasonable increase in the stiffness of the suspension spring can improve the steering stability of the car to a certain extent.

1. Introduction

Undergraduate Baja racing car is a small off-road racing car with single seat, mid-engine and rear drive. The handling stability of the car determines the convenience of the car's handling and the dynamic performance under extreme conditions, so it is very important to the overall performance of the car. Since the road on which the Baja racing car is driven is a non-paved road, the road has large undulations, potholes, and complex road conditions, so the suspension system is extremely demanding, and the suspension system needs to be able to effectively absorb the impact of the road. Suspension stiffness, as an important parameter of the suspension system, also has an important impact on the overall handling and stability of the car.

From the point of view of feasibility and economy, the design and manufacture of multiple sets of suspension systems with different stiffnesses will be very tight in the short preparation period; and the cost of manufacturing multiple sets of suspension systems with different stiffnesses is very high. Therefore, in order to determine the optimal stiffness of the suspension system in a relatively short period of time, this paper adopts virtual prototype simulation analysis, and designs simulation tests of three typical working conditions. By comparing the parameters of various states of the racing car, the effect of suspension stiffness is explored. The influence of the Baja racing car's handling stability.

2. Model building

Based on the Adams/car software developed by MSC software, this paper establishes a multi-body dynamics simulation model, and establishes models of front suspension, rear suspension, steering, transmission, front and rear tires, etc.; and establishes the corresponding subsystems, and assembles the subsystems Assemble into a complete vehicle model. And match the communicator for simulation operation. Table 1 shows the parameters of the complete Baja racing car, and Figure 1 shows the complete model of the Baja racing car.

Table 1. Vehicle parameters of Baja Racing.

Project	Parameter
Wheelbase /mm	1470
Front track /mm	1250
Rear track /mm	1250
Vehicle quality /kg	175
Axle load ratio	42:58

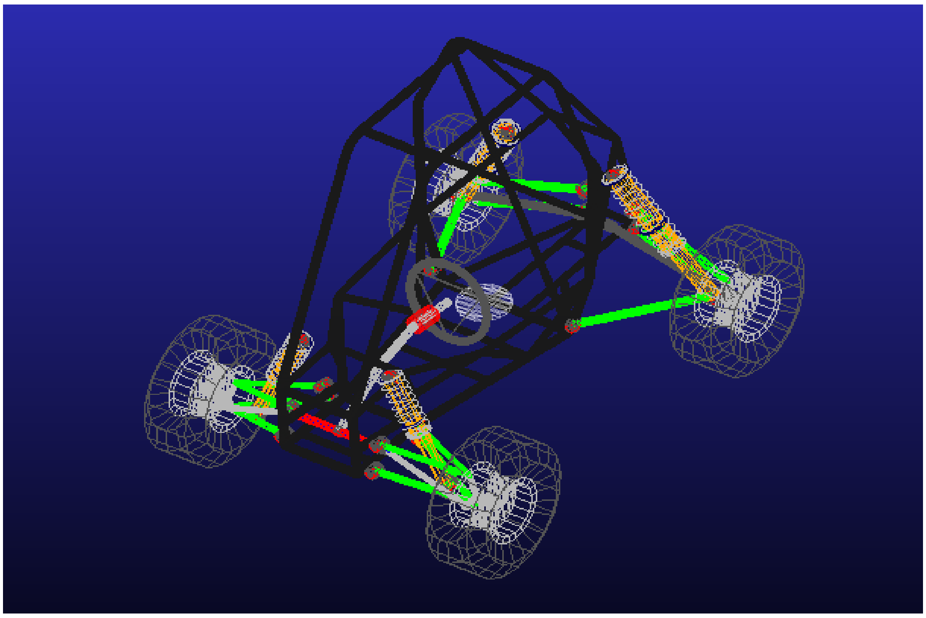

Fig 1. Baja racing car model.

3. Suspension coil spring stiffness calculation

3.1 The elastic characteristics of the suspension.

(1) Determine suspension offset frequency

Suspension bias refers to the natural frequency of the car's sprung mass without damping, also known as the natural frequency; the bias frequency of different types and uses of cars is different. Before calculating the spring stiffness, a suitable suspension offset frequency should be selected based on the vehicle parameters. Table 2 shows the deviation frequency range of different types of racing car suspensions.

Table 2. Different types of vehicle suspension offset frequency range.

Vehicle Type	Offset frequency(Hz)
Ordinary car	0.5-1.5
Moderate negative lift racing	1.5-2.0
Off-road racing	1.5-2.5
High negative lift racing car	3.0-5.0 above

The selection principle of offset frequency is as follows:

①Different front and rear to avoid resonance.

②For ordinary cars, for the sake of ride comfort, the front is low and the rear is high.

③For racing cars, due to handling performance considerations, generally the front is high and the rear is low.

Taking the above factors into consideration, the suspension frequency is finally determined as:

$$n_1 = 2.3Hz \quad n_2 = 2.4Hz \tag{1}$$

(2) The sprung mass of the axle

The masses on the front and rear axles areM_{s1}, M_{s2}, and the loads on the front and rear axles of the suspension are 42% and 58% respectively.

(3) Calculate the stiffness of the unilateral spring

$$C = (2\pi n)^2 M_s/2 \tag{2}$$

(4) Mass load caused by sprung mass

$$F_z = M_{s1}/2g \tag{3}$$

(5) Suspension static deflection

From$f_c = F_z/C$, the static deflection of the front and rear suspension is obtained.

3.2 Suspension stiffness calculation

The front suspension of the Baja racing car adopts a double wishbone independent suspension. According to the literature, according to the characteristics of the suspension guiding mechanism, the stiffness C_s and the force F_s of the coil spring are calculated. Figure 2 shows the mechanical model of the double wishbone independent suspension.

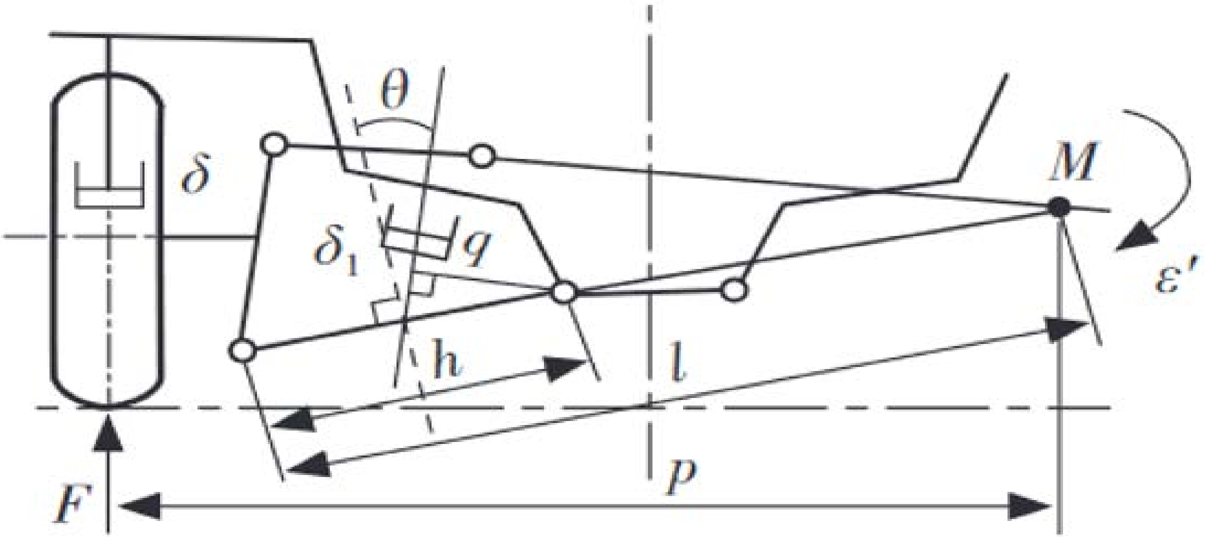

Fig 2. Mechanical model of double wishbone independent suspension.

(1) Find the force F_s of the coil spring

F is the vertical force of the ground against the wheel, and ε^' is the angular virtual displacement of the wheel when the wheel is moving. According to the principle of virtual displacement, the relationship is as follows:

$$F \cdot (p \cdot \varepsilon') = F_s \cdot \left(\frac{l \cdot \varepsilon\prime}{b} \cdot q\right) \tag{4}$$

$$F_s = F \cdot \left(\frac{p \cdot h}{l \cdot q}\right) \tag{5}$$

In the formula, p- is the distance between the suspension instant center ground projection point and the tire grounding mark center; h- is the length of the suspension arm in the front view; l- is the distance from the suspension arm ball pin to the instant center in the front view; q -Is the distance from the spring installation point of the lower swing arm to the twisting point in the lower swing arm.

(2) Find the coil spring stiffness C_s

The angular virtual displacement ε'will cause the vertical force increment ΔF on the wheel, and also the spring force increment ΔF_s in the coil spring.

$$\Delta F = C \cdot (p \cdot \varepsilon') \tag{6}$$

$$\Delta F_s = C_s \cdot \left(\frac{l \cdot \varepsilon'}{h} \cdot q\right) \tag{7}$$

Let,

$$F = \Delta F = C \cdot (p \cdot \varepsilon') \tag{8}$$

$$F_s = \Delta F_s = C_s \cdot \left(\frac{l \cdot \varepsilon'}{h} \cdot q\right) \tag{9}$$

Substituting formula (8) and formula (9) into formula (5), the relationship between the stiffness of the spring wire and the stiffness of the coil spring is obtained

$$C_s = C \cdot \left(\frac{p \cdot h}{l \cdot q}\right)^2 \tag{10}$$

4. The Effect of the Spring Rigidity of the Front Suspension on the Stability of Racing Car

The simulation experiment road uses a 2d_flat road, which can more intuitively reflect the steering stability of the car. In order to analyze the influence of the front suspension stiffness on the steering stability of the car, the suspension spring stiffness is increased and reduced by 30% for simulation experiments.

4.1 Steering wheel angle step input test

In this simulation experiment, the car is set to a fully loaded state, the initial speed is selected to be 40km/h, and the car is kept straight at a constant speed. When the car is driving for 2 seconds, quickly turn the steering wheel and maintain the 50° corner unchanged until the car reaches a steady state again. Among them, keep 5s in the middle position, and the simulation time is 10s. The time curve of the steering wheel angle is shown in Fig.3, and the result of the change in the spring stiffness of the front suspension is shown in Fig.4-6. Among them, ss is the change curve of the actual linear stiffness value of the suspension spring, ss1 is the change curve of the spring stiffness value increased by 30%, and ss2 is the change curve of the spring stiffness decreased by 30%.

The lateral acceleration change of the vehicle body is shown in Fig. 4, the yaw rate is shown in Fig. 5, and the body roll angle change is shown in Fig. 6. From Fig.4 to Fig.6, it can be found that the transient response performance of the car's handling changes with the change of the suspension spring stiffness. Increasing the spring stiffness can reduce the value of the car's lateral acceleration, yaw rate and roll angle amplitude. Therefore, it is conducive to the improvement of the overall handling stability of the car; on the contrary, as the spring stiffness decreases, the lateral acceleration, yaw rate and roll angle amplitude will increase with the decrease of the spring stiffness, resulting in a decrease in the handling stability of the car.

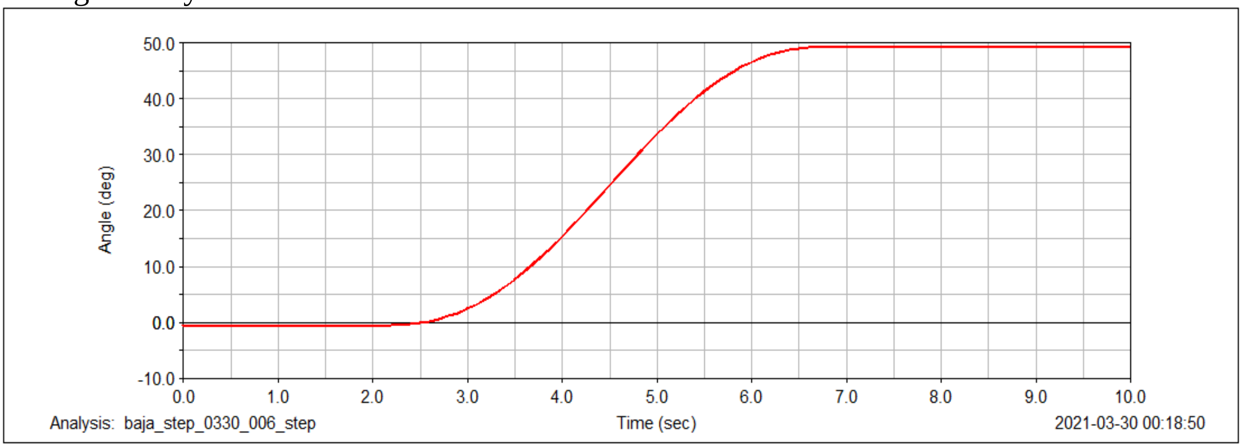

Fig.3 Steering wheel angle curve.

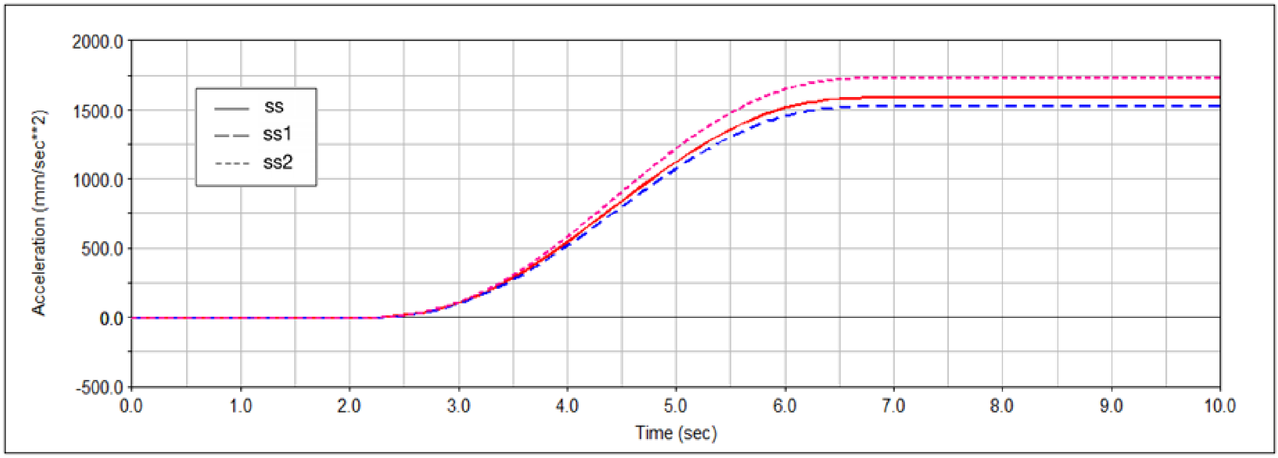

Fig.4 Time curve of lateral acceleration.

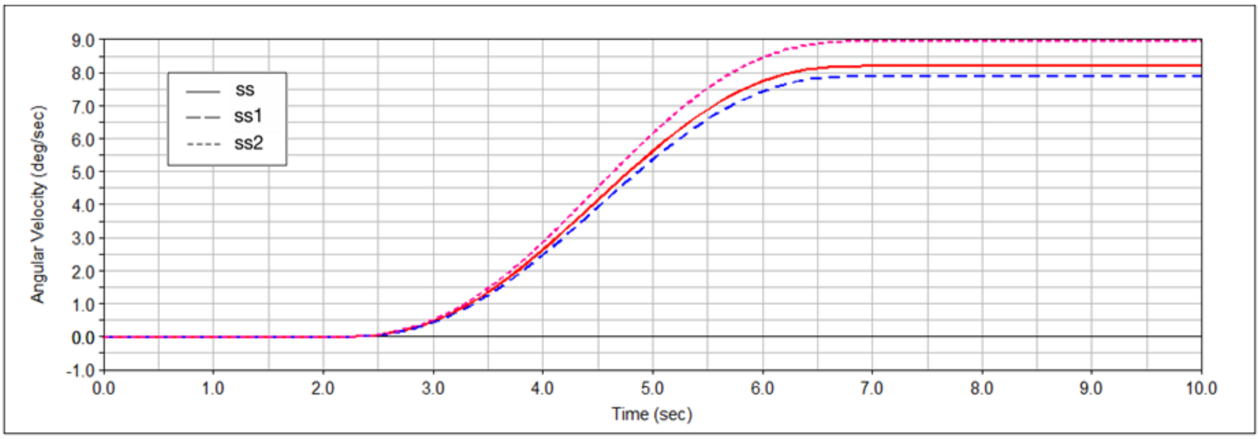

Fig.5 Time curve of vehicle body yaw rate.

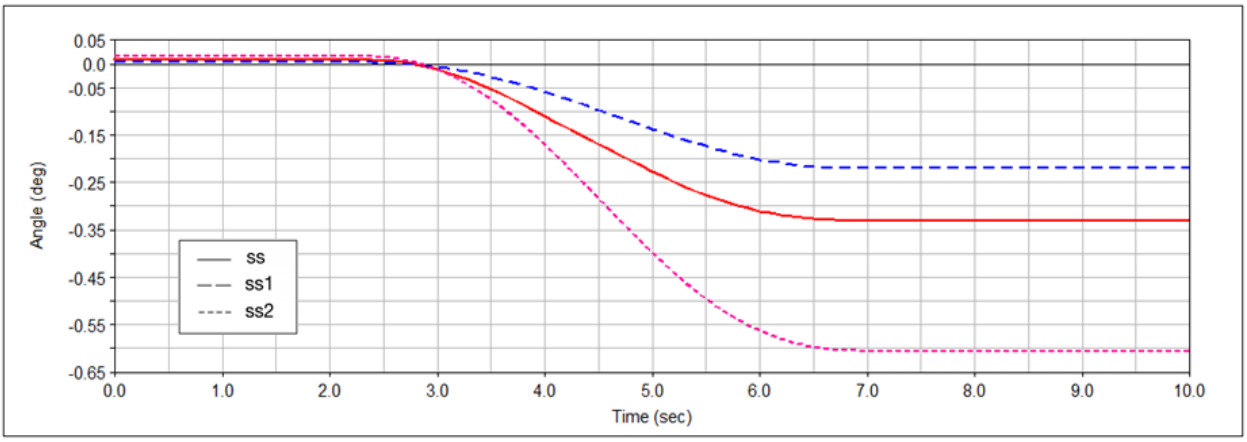

Fig.6 Time curve of body roll angle.

4.2 Steering wheel angle pulse input test

In this simulation test, the car drove straight at a constant speed of 40km/h, gave the steering wheel a 50° angle in 1s, and then quickly returned to the center. Among them, the pulse width is 0.5s, the middle position is maintained for 0.5s, and the simulation duration is 10s. The time curve of the steering wheel angle is shown in Fig.7, and the result of the change in the spring stiffness of the front suspension is shown in Fig.8-10. Among them, ss is the change curve of the actual linear stiffness value of the suspension spring, ss1 is the change curve of the spring stiffness value increased by 30%, and ss2 is the change curve of the spring stiffness decreased by 30%.

The change in lateral acceleration of the vehicle body is shown in Fig.8, the yaw rate is shown in Fig.9, and the change in the vehicle body roll angle is shown in Fig.10. From Fig.8-10, it can be found that whether the suspension spring stiffness is increased or decreased, the car can return to a stable state in a short time, but when the spring stiffness increases, the lateral acceleration and lateral acceleration of the car Both the swing angle speed and the roll angle amplitude are reduced, so that the car has good handling stability; when the spring rate is reduced, it will cause the lateral acceleration, the yaw angle velocity, and the roll angle amplitude to increase, which in turn leads to The handling stability of the car is reduced.

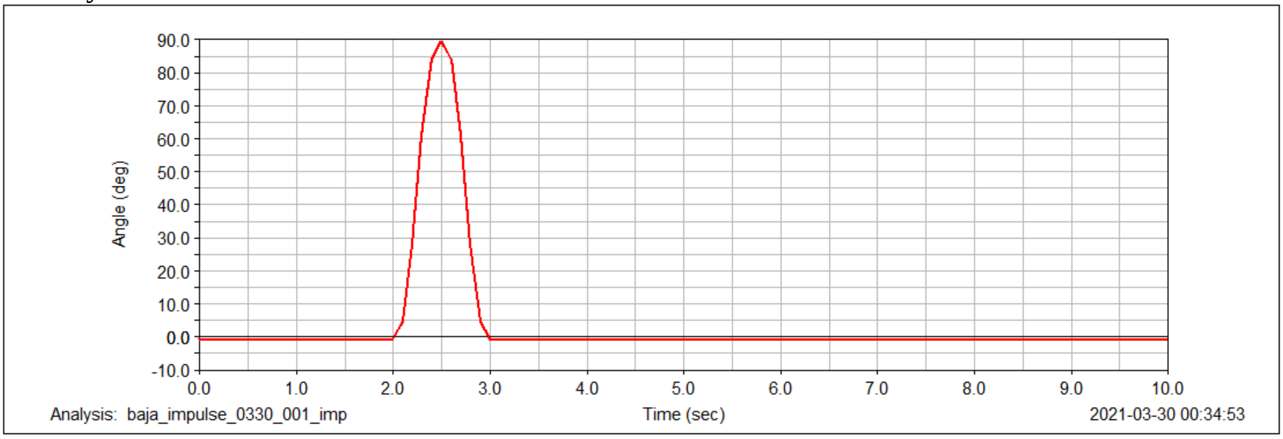

Fig.7 Steering wheel angle curve.

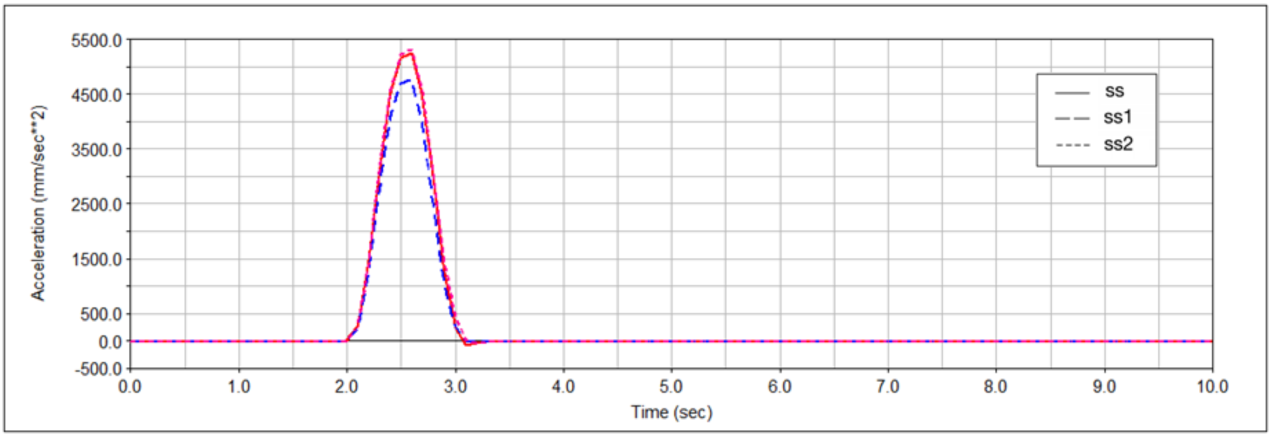

Fig.8 Time curve of lateral acceleration.

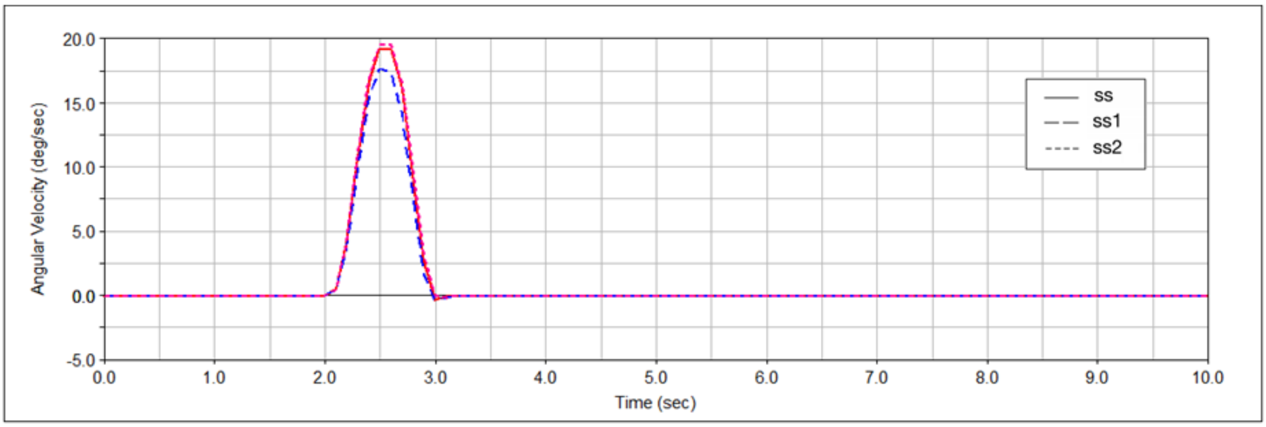

Fig.9 Time curve of vehicle body yaw rate.

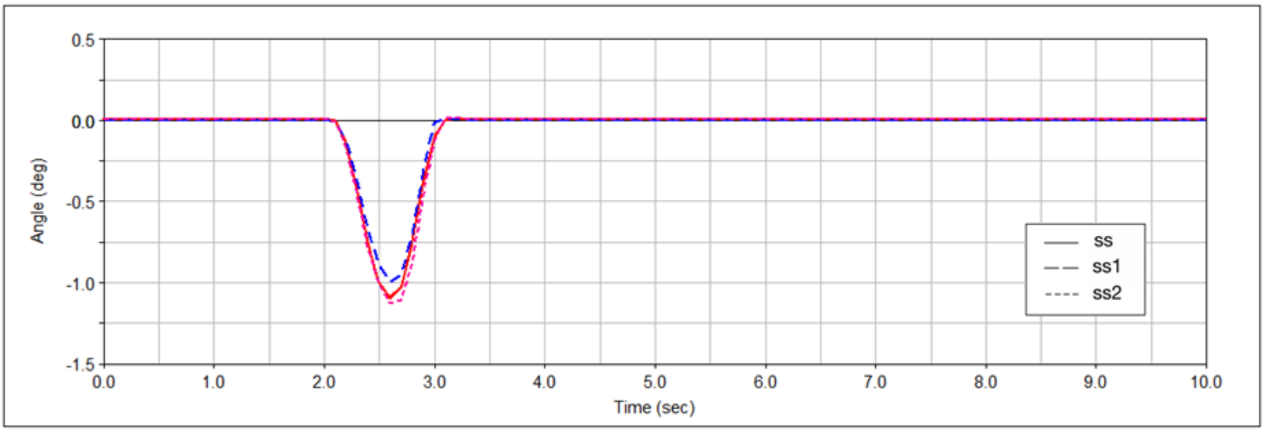

Fig.10 Time curve of body roll angle.

4.3 Single shift line test

When the simulation was carried out, the initial setting value of the vehicle speed was 40km/h, and the vehicle was driven straight at a constant speed. After driving for 1s, the steering wheel was rotated to the maximum value of 50° in a sine wave angle. Among them, the middle position is kept for 8s, and the simulation time is 10s. The time curve of the steering wheel angle is shown in Fig.11, and the results of the front suspension spring stiffness change are shown in Fig.12-14, where ss is the actual linear stiffness change curve of the suspension spring, and ss1 is the spring stiffness increased by 30 % Change curve, ss2 is the change curve of spring stiffness reduced by 30%.

The lateral acceleration change of the vehicle body is shown in Fig. 12, the yaw rate is shown in Fig. 13, and the body roll angle is changed as shown in Fig. 14. It can be found from Fig.12-14 that when the spring stiffness changes, the transient response performance of the car also changes. When the spring stiffness increases, the lateral acceleration, yaw rate, and roll angle amplitude are all reduced, which improves the handling stability of the car to a certain extent; when the spring rate is reduced, the lateral acceleration, yaw rate, and side the amplitude of the angle of inclination is increased, which makes the steering stability of the car worse.

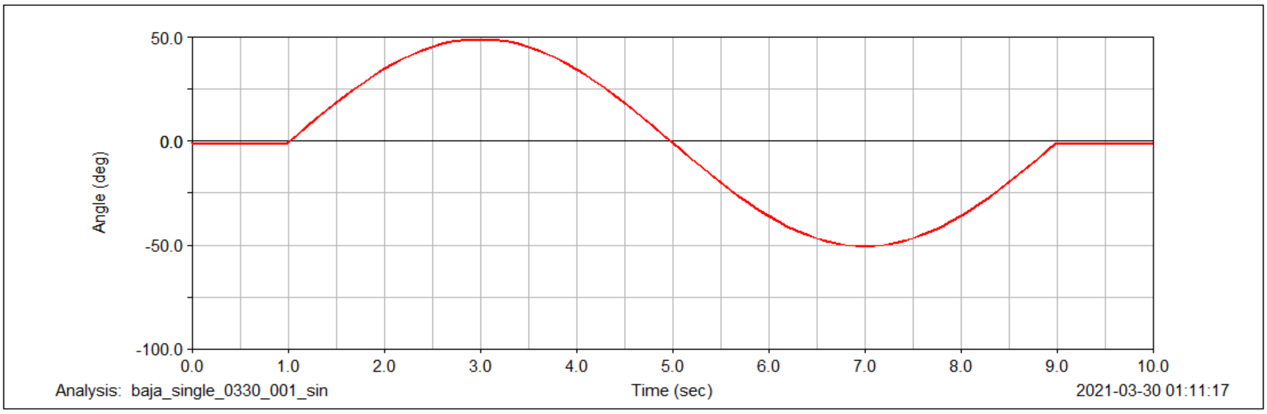

Fig 11. Time curve of steering wheel angle.

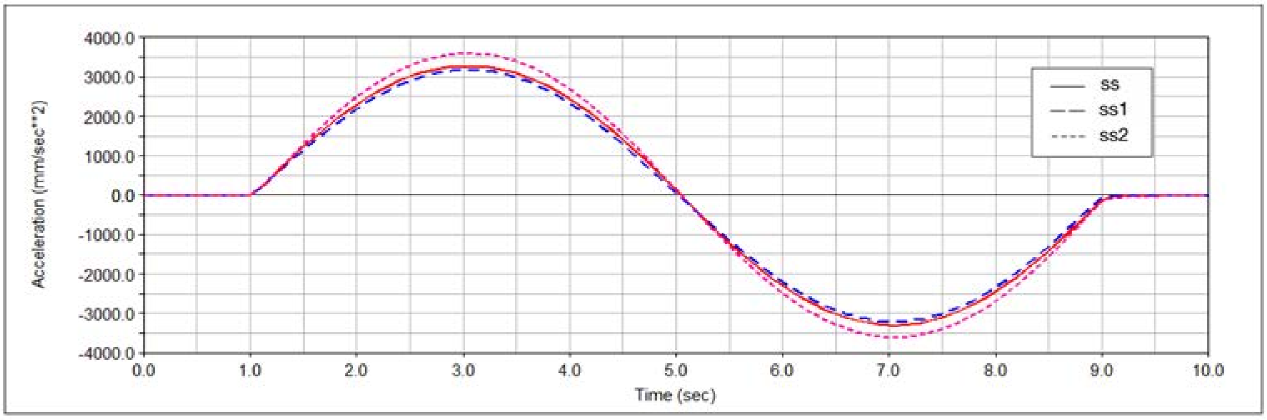

Fig 12. Time curve of lateral acceleration.

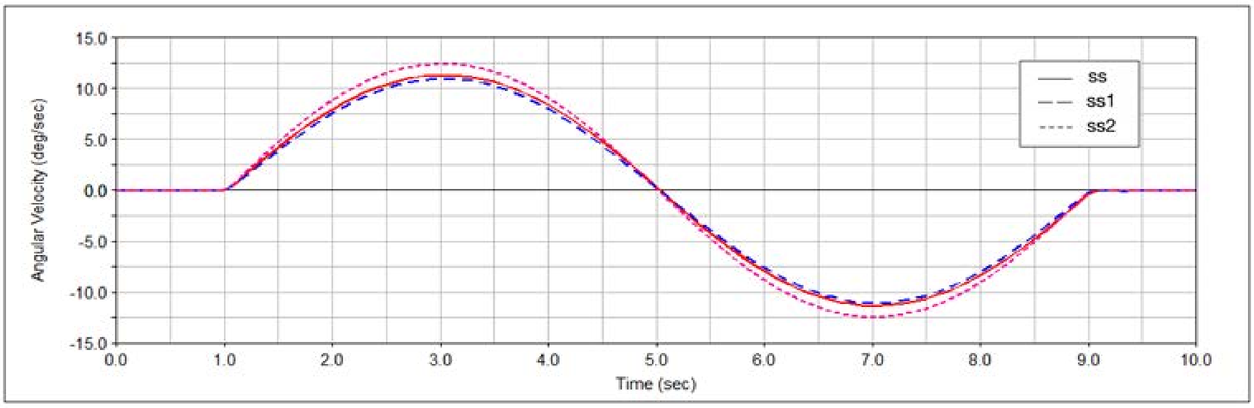

Fig 13. Time curve of yaw rate.

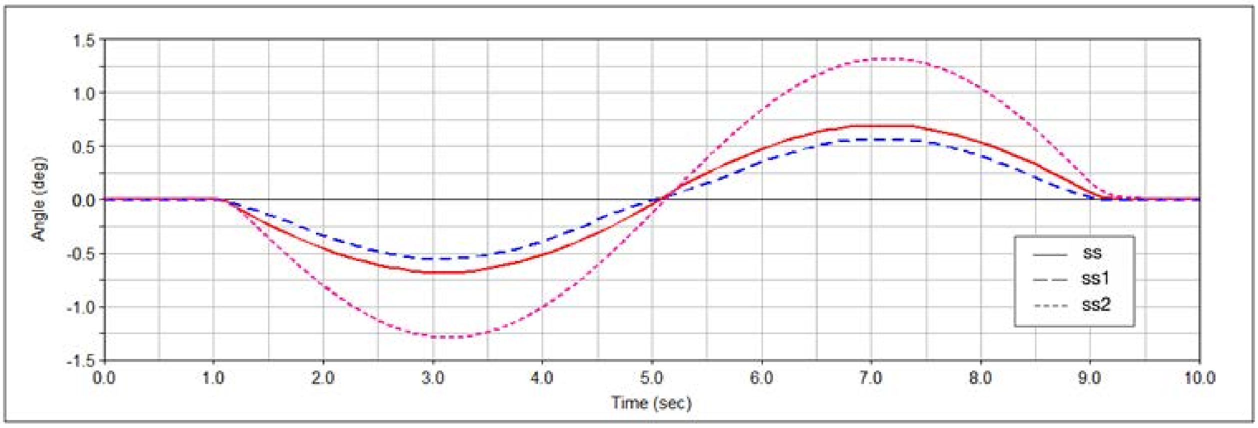

Fig 14 Time curve of body roll angle.

5. Summary

This paper uses the Adams/Car module to establish a multi-rigid body system model of the vehicle, analyzes the response of the suspension's spiral spring stiffness parameter changes to the various state variables of the vehicle body, and then analyzes the influence on the handling stability of the vehicle. From the test results, it can be concluded that by increasing the stiffness of the suspension coil spring, the lateral acceleration, yaw rate and the amplitude of the body roll angle of the car will all decrease; and when the stiffness of the suspension coil spring decreases, the side of the car will decrease. The amplitudes of acceleration, yaw rate and body roll angle have all increased. That is, increasing the spring stiffness of the front suspension will improve the handling stability of the car, and reducing the spring stiffness of the front suspension will reduce the handling stability of the car. This study provides ideas on how to improve the handling and stability of Baja racing cars by adjusting the stiffness of the suspension, and preliminary experiments have also been carried out.

In the process of researching and modeling in this article, it was found that the model had shortcomings, which was simplified and ignored in many aspects, which was different from the actual situation.

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