

# Study on kinematic and compliance test of suspension

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**Abstract.** Chassis performance development is a major difficulty in vehicle research and development, which is the main factor restricting the independent development of vehicles in China. These years, through a large number of studies, chassis engineers have found that the suspension K&C characteristics as a quasi-static characteristic of the suspension provides a technical route for the suspension performance R&D, and the suspension K&C test has become an important means of vehicle benchmarking, optimization and verification. However, the research on suspension K&C test is less in china, and the test conditions and setting requirements vary greatly from OEM to OEM. In this paper, the influence of different settings on the characteristics of the suspension is obtained through experiments, and the causes of the differences are analyzed; in order to fully reflect the suspension characteristics, the author recommends the appropriate test case and settings.

## 1 Definition of K&C Characteristics of Suspension

K is the acronym for the word Kinematics. It represents the geometric kinematic characteristics of the suspension. Its variation is related to the change in the suspension positioning parameters caused by the displacement, and these parameters are mainly related to the hard point and rod of the suspension.

C is the acronym for the word Compliance, it represents the elastic kinematic characteristics of the suspension. Its parameter variation is related to the change in the suspension positioning parameters caused by the force, and these parameters are mainly related to the hard points of the suspension, the stiffness of the parts and the rigidity of the rubber bushings [2].

## 2 Device for measuring K&C characteristics of suspension

*2.1 K & C's test system typically consists of five main subsystems:*

*2.1.1 Wheel platform.* The dual-axis K & C test rig has four wheel platforms, it can apply a displacement or force constraint to the tread of each tire. Each platform can provide vertical, lateral, longitudinal, rotation and roll (MTS test bed) and other degrees of freedom. The platform needs to have high enough stiffness to reduce the measurement error of the system.

*2.1.2 Body clamping platform.* Body clamping platform has a steel base, the car is fixed to the base by four calipers, the relative movement between the body clamping platform and the wheel platform enables loading of the suspension.

*2.1.3 Steering and brake actuators.* The movement of the steering mechanism is done by robot, and its main function is to fix or turn the steering wheel; the main role of the brake actuator is to control the rise and fall of the brake pedal in order to achieve the function of the brake system.





**Figure 1** K&C Test Platform

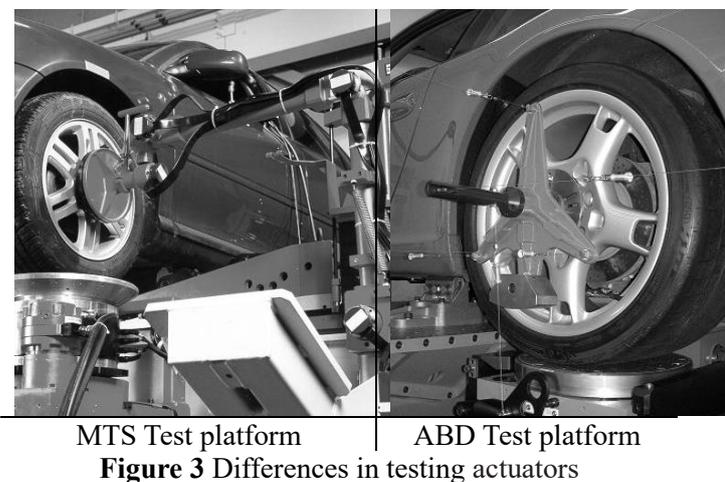
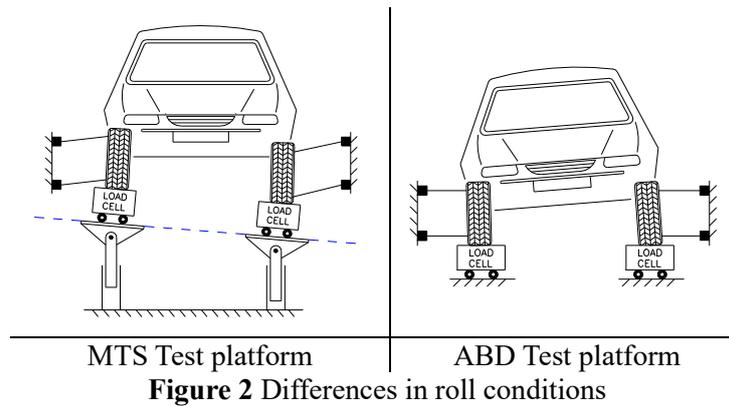
**2.1.4 Position and load sensors.** Both the wheel platform and the body platform are equipped with displacement sensors and force and torque sensors, it can measure the displacement of the body, the tire at the location of the displacement and force; a displacement sensor is mounted on the wheel to measure the wheel hub displacement, it consists of three translational (longitudinal, lateral, vertical displacement) and three rotations (wheel rotation angle, toe angle, camber angle); the steering robot can measure the displacement, force and torque parameters of the wheel.

**2.1.5 Control and instrumentation.** Including the system control cabinet, hydraulic oil source and test control computer.

At present, there are four kinds of domestic K & C test platform, including the British ABD test platform [3], MTS test platform [4] [5], Kong Hui test platform [6] and the British Lotus test platform, customers of which the ABD and MTS test platform have a higher degree of recognition, the main differences between loading and measurement are shown in the Table 1, comparison of roll load conditions shown in Figure 2, the comparison of the test mechanism is shown in Figure 3, the contents of the tests described in this article are completed on the ABD test platform.

**Table 1** Comparison of two kinds of K & C test platform

project	MTS	ABD
Vertical force loading (parallel wheel jump, roll)	Body platform fixed Wheel platform movement	Body platform movement Wheel platform fixed
testing actuators	Rocker type	Pull line type
Lateral force loading	Body platform fixed Wheel platform movement	same as MTS
longitudinal force loading	Body platform fixed Wheel platform movement	same as MTS
aligning torque loading	Body platform fixed Wheel platform movement	same as MTS
Steering force loading	Body platform and wheel platform fixed, steering robot steering	same as MTS



### 2.2 K & C test conditions and parameters of Suspension

The suspension K&C test conditions mainly include the following six:

**2.2.1 Vertical loading condition - parallel wheel jump.** Explanation of working conditions: The left and right wheels are jumping up or down at the same time as the body. It can analyze the impact of the load height on the suspension parameters.

**2.2.2 Vertical loading conditions - roll conditions.** Explanation of working conditions: Body roll, The left and right wheels move upward and downward relative to the vehicle body, respectively. It can be used to analyze the effect of body roll on suspension parameters.

**2.2.3 Steering condition.** Explanation of working conditions: The torque is applied at the steering wheel, and the left and right wheels are free to rotate. It can be used to analyze the influence of the steering wheel angle on the suspension parameters.

**2.2.4 Lateral force condition.** Explanation of working conditions: The left and right wheels load the lateral load at the tire ground (or later), which can be used to analyze the effect of the lateral force on the suspension.

**2.2.5 Aligning torque condition.** Explanation of working conditions: The left and right wheels are loaded aligning torque at the wheel ground point and can be used to analyze the effect of aligning torque on the suspension parameters caused by the suspension distance and the tire drag.

**2.2.6 Longitudinal force condition.** Explanation of working conditions: The left and right wheels load the longitudinal force at the wheel ground point, which can be used to analyze the effect of the braking force on the suspension at the tire's ground point when the vehicle is braked.

The above conditions 1、2 can be divided into demolition、installed stability bar characteristics test, condition 3 can be divided into open and close power characteristics test, condition 4、5、6 can be divided into the same direction and reverse characteristic test. The following conditions and main

suspension parameters <sup>[7]</sup>

**Table 2** K&C Test condition and parameter list

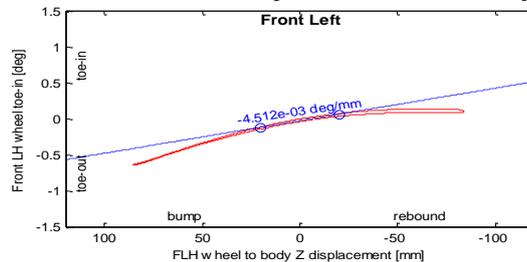
Vertical loading conditions (demolition, loading stabilizer bar)	Suspension stiffness [N/mm]
	Suspension friction [N]
	Ride stiffness [N/mm]
	Tire radial stiffness [N/mm]
	Toe angle [deg/m]
	Camber angle [deg/m]
	Geometric roll center [mm]
	Longitudinal displacement of the wheel center [mm/m]
	Longitudinal displacement of tire ground [mm/m]
Roll conditions (demolition, loading stability bar)	Suspension stiffness [N/mm]
	Toe angle [deg/deg]
	Camber angle [deg/deg]
	Suspension roll stiffness [Nm/deg]
	Total roll stiffness [Nm/deg]
	Geometric roll center [mm]
Steering working conditions (Open, off engine)	Transmission ratio [/]
	Steering friction [Nm]
	Friction radius [mm]
	Mechanical distance [mm]
	Ground pitch deviation [mm]
	The main pin offset from the hub [mm]
	Kingpin caster Angle [deg]
	Kingpin inclination [deg]
Lateral force (co-directional, reverse)	Wheel hub flexibility [mm/kN]
	Toe Angle kindliness [deg/kN]
	Camber Angle kindliness [deg/kN]
	Tire ground lateral stiffness [N/mm]
	Force roll center height [mm]
Correction force condition (synthetic, reverse)	Toe Angle kindliness [deg/ kNm]
	Camber Angle kindliness [deg/ kNm]
Longitudinal force (co-directional, reverse)	Wheel hub flexibility [mm/kN]
	Toe Angle kindliness [deg/kN]
	Camber Angle kindliness [deg/kN]
	Wheel rotation changes [deg/kN]
	Tire ground vertical stiffness [N/mm]
	Anti-Dive/Squat [deg]

Followed by vertical loading conditions - parallel wheel jump and lateral force loading conditions as an example, to explain the suspension of the K and C characteristics of the specific parameters and significance.

### 2.3 Vertical loading conditions

The change in toe angle: As in the condition the left and right wheels are moving together, if the left

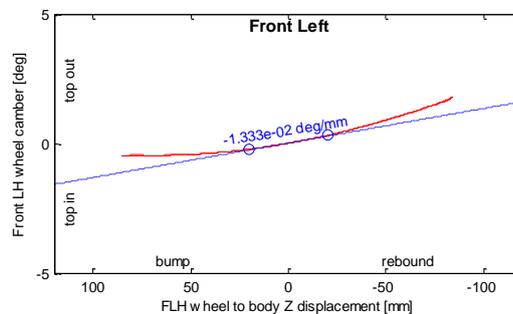
and right suspension changes are symmetrical, the toe angle in any condition will not cause changes in vehicle steering. But the toe angle will affect the lateral force of the tire, and has an important impact on tire wear. So in the usual condition the initial toe angle can not be too large and the change with the wheel jump is small. This can reduce tire wear and improve vehicle stability.



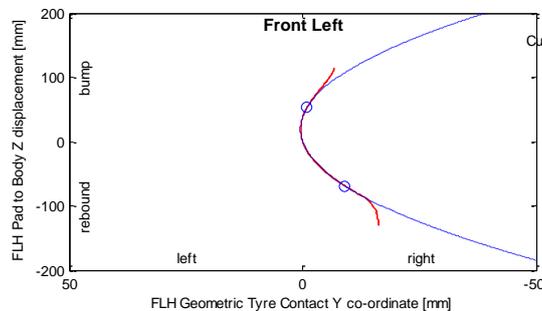
**Figure 4** The characteristics of the toe angle changes with the tire

Figure 4 is a car model of the front suspension in the parallel round jump condition of toe angle changes, from the figure you can see the size of about  $-4.5 \text{ deg/m}$ . When the wheel jumps upwards relative to the body, the toe angle will decrease. This trend is mainly to make the front suspension produce some understeer when the wheels in the roll.

The change in camber angle: It is similar to the change in the toe angle under this condition, for example, if the left and right changes are symmetrical, then the camber change does not cause the vehicle to turn; in order to reduce the lateral force change, we usually require the camber angle to change with the wheel beats smaller, but taking into account the fact that the characteristic of outside wheels are grounded when the vehicle is in roll (the tire relative to the ground camber angle is smaller, the better the carrying capacity, the better the grounding characteristics), when the wheel jumps, the camber angle should have some compensation (Top In), this can reduce the camber angle of tire and ground.

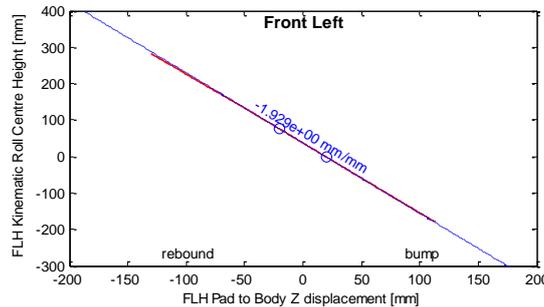


**Figure 5** Camber Angle along with the change of the tire characteristics



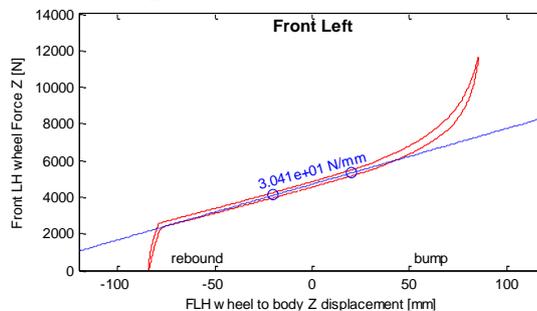
**Figure 6** The change of the wheel track

Change in track: This parameter indicates the lateral displacement of the tire gating point with the change of surface of the tire, the greater the value, the greater the degree of wear on the tire. While the dynamic characteristics of the tire will also be affected.



**Figure 7** The variation characteristics of the height of the roll center

The height of the roll center: It is an important parameter to represent the roll characteristics, when the roll center is high, the vehicle's roll gradient will be reduced [8], but this will increase the track change. As the front suspension is also responsible for turning, at the same time excessive wheel track changes can cause premature wear on the front wheels. So the height of the roll center of the front suspension is generally lower, while the height of the rear center of the rear suspension is higher.



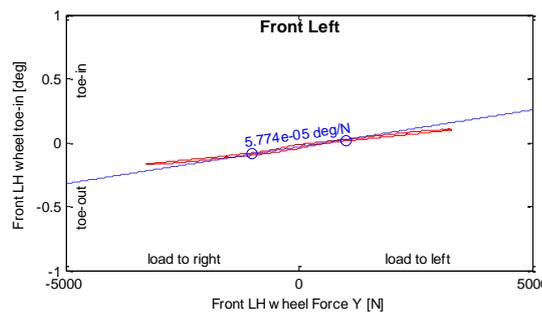
**Figure 8** Suspension stiffness characteristics

Suspension stiffness characteristics: This is one of the important parameters of suspension vertical stiffness of characterization, it determines the partial frequency vibration of the suspension with the sprung mass. Higher bias frequency will cause the suspension to be "hard", although this will help improve the stability of the operation, but also reduce the ride comfort. Passenger car suspension frequency design range of 1.2-1.6Hz.

Suspension friction: This parameter indicates the friction characteristics of the suspension, it represents the vertical force difference when the suspension jumps up and down (ie hysteresis height). This parameter mainly affects the dynamic stiffness characteristics of the suspension, the greater the friction, the greater the dynamic stiffness, The ride comfort of the suspension also decreases.

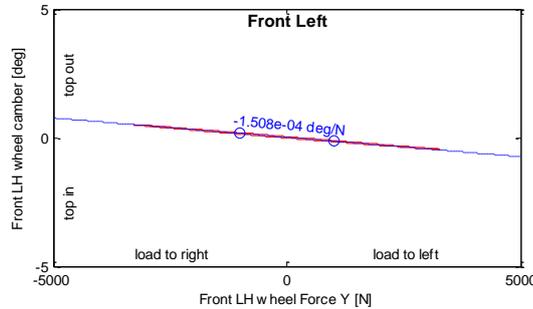
*2.4 Lateral force loading condition*

The toe angle changes: This parameter characterizes the change characteristics of the toe angle when the suspension is subjected to lateral force, the actual Angle of the wheel will change with the changes of toe angle, of course, it will also affect the equivalent side of the wheel stiffness and the lack of vehicle steering characteristics [9].



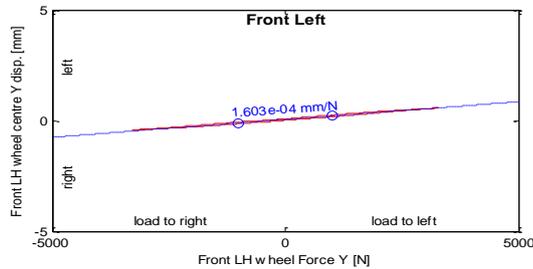
**Figure 9** The variation characteristics of the toe angle of the left front suspension with the lateral force

Generally we require the suspension to have a certain lateral force to the understeer trend, for example, when the left front wheel is forced to the left lateral force, the toe angle changes to toe in, and the left rear wheel changes to toe out when the left lateral force is left.



**Figure 10** The variation of camber angle with lateral force

The camber angle changes: The change in camber angle represents the stiffness of the suspension, while affecting the grip of the wheel.

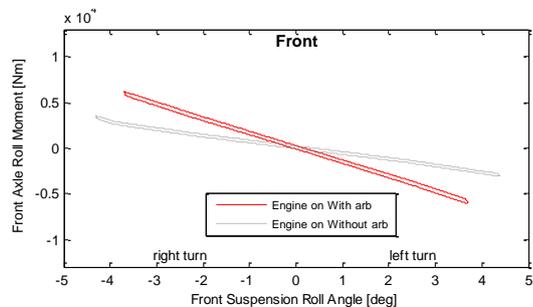


**Figure 11** Lateral Stiffness Characteristics of Suspension

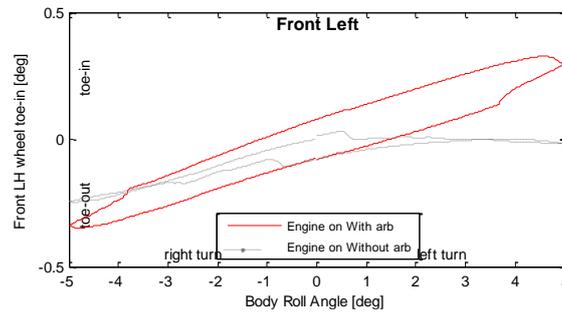
Suspension lateral stiffness: The lateral stiffness of the suspension will affect the steering response performance of the vehicle<sup>[10]</sup>, higher stiffness is conducive to the improvement of response speed. If the lateral stiffness of the front suspension is low, the vehicle steering response is slow, and if the lateral stiffness of the rear suspension is low, it is easy to lead to poor follow-up of vehicles, poor stability, and even secondary steering and so on.

*2.5 Effect of test setup on suspension characteristics*

Different experimental settings have different effects on the characteristics of the suspension, therefore it needs to be specified in the course of the test. For example, the test of disassembling the stabilizer bar under the roll condition, besides the influence of stabilizer bar in suspension roll stiffness, it will also affect the suspension roll steering, that is, the stabilizer bar will cause additional changes in the toe angle, as shown in Figure 13.

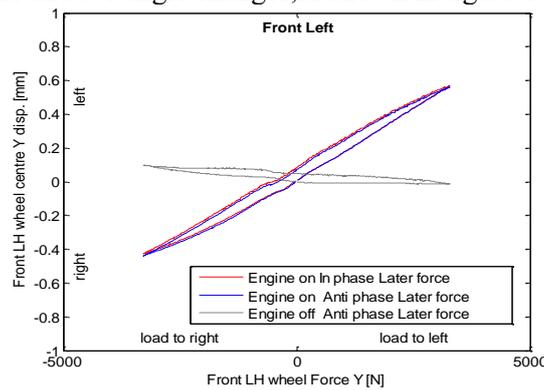


**Figure 12** The influence of stabilizer bar for suspension roll stiffness



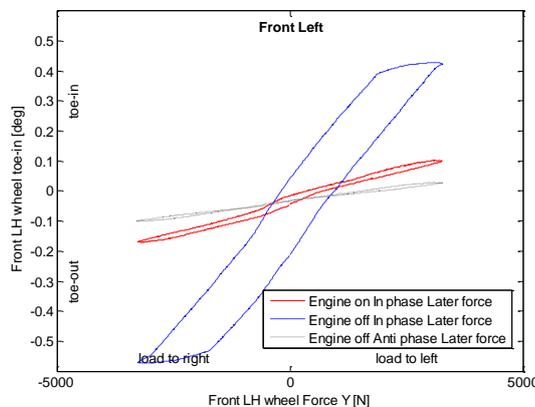
**Figure 13** Influence of stabilizer bar on the change of tire's toe angle

In the reverse lateral force, the reverse aligning torque and the same longitudinal force condition, suspension system on both sides of the force offset with steering system and sub-frame, the opening of the engine (switch steering assist) has little effect on the test results. But in the same lateral force and the same aligning torque condition, the force of suspension system, steering system and deputy frame will be superimposed on each other, steering system and subframe will produce the overall displacement, whether the engine is switched on or off (switch steering assist) will significantly affect the suspension stiffness and toe angle changes, as shown in figure 14-17.



**Figure 14** Influence of different settings on lateral stiffness of suspension

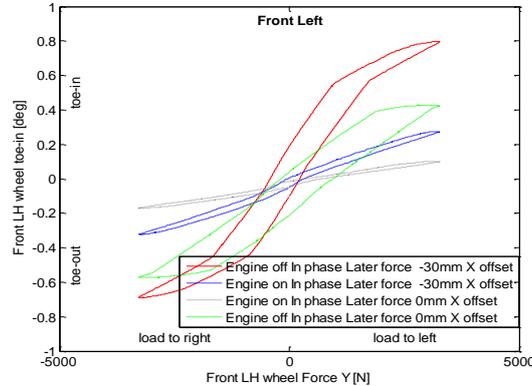
Whether the engine is switched on or off (switch steering assist) has no significant effect on the lateral stiffness of the suspension, but there is a significant difference between the same direction and the reverse loading.



**Figure 15** The effect of the different settings on the lateral toe angle of the suspension

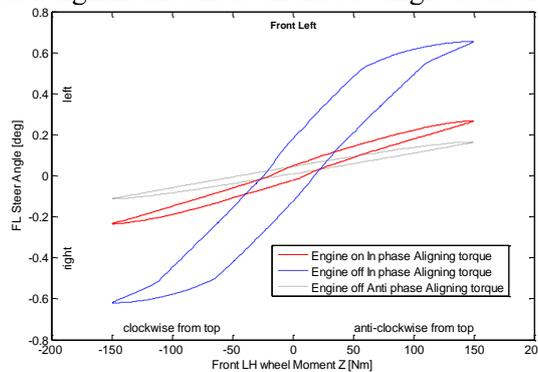
Whether the engine is switched on or off (steering power steering) has a great influence on the toe angle of the lateral force of the suspension, and there is a significant difference between the same

direction and the reverse loading.



**Figure 16** The effect of the different settings on the toe angle of the suspension

The lateral force bias has a significant effect on the toe angle of lateral force.



**Figure 17** Influence of different settings on the toe angle of the aligning torque of suspension

Whether the engine is switched on or off (switch steering assist) has a significant effect on the toe angle of aligning torque of suspension, and there is also a significant difference between the same direction and the reverse loading. Through comparative studies, we found that if we want to fully reflect the characteristics of the suspension system and the steering system, we need to conduct the thorough research to the test conditions and test set. At the same time, the test must be able to reflect the influence of the auxiliary characteristics, the sub-frame, the stabilizer bar and so on, and obtain the specific parameters of the parts and components by the decomposition. With these, it can provide support for benchmarking and development verification.

The following is the author recommended test conditions and settings based on the test platform of his unit.

Test conditions		Set description (0 = NO, 1 = YES)			
		Brake open	engine on	Front stabilizer bar connection	rear stabilizer bar connection
Vertical loading	Parallel wheel jump	1	1	1	1
				0	0
Vertical loading	Roll	1	1	1	1
				0	0
Steering	With power	1	1	1	1
	No power	1	0	1	1
Lateral force	synthetic	1	1	1	1

loading		1	0	1	1
	reverse	1	1	1	1
aligning torque loading	synthetic	1	1	1	1
	reverse	1	0	1	1
Longitudinal force loading	synthetic	1	1	1	1
	reverse	1	1	1	1

The above conditions and settings have the following advantages:

The displacement of the stabilizer bar can be compared with the suspension stiffness of the suspension by adjusting the setting of the stabilizer bar in the roll condition;

The influence of the steering system on the characteristics of the suspension system can be investigated by controlling the setting of the engine on and off in the steering condition;

Through the reverse lateral force and the reverse aligning torque condition can study the suspension system itself caused by the suspension of the deformation characteristics;

Through the same lateral force 、 the same aligning torque condition and Engine switch setting can examine the steering system and sub-frame on the suspension system characteristics;

Through the same lateral force 、 the same aligning torque condition and Engine switch setting can examine the effect of the steering system on the characteristics of the suspension system;

Through the reverse longitudinal force condition can study of steering system and auxiliary frame of suspension vertical stiffness and the influence of longitudinal force.

### 3 Summary

This paper first introduces the definition of suspension K & C characteristics and its important role in its chassis development ,simultaneously there is a comparative study of the test equipment; then the K & C test related conditions and the meaning of the parameters were described. By comparing the test data, it was shown that the test setup had a significant effect on the test results. In order to more fully reflect the characteristics of the suspension, the author recommended a set of test conditions and specific settings, through this method can get the suspension system more comprehensive characteristics, but also for the development of the chassis to provide support.

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