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Research of VC Based Simulation Test System for Automotive ABS

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Abstract

A simulation test and analysis system for ABS control strategy was developed through the joint of VC++6.0 development platform and MATLAB/Simulink simulation platform. And the simulation test for ABS control strategy on four typical roads was carried out. Besides, the test results were analyzed. The test results showed that the system is able to give a good simulation of vehicles and roads and has the capacity of offering a good detection analysis.

Keywords*: ABS, Visual C++, Matlab/Simulink, simulation test*

1. Introduction

Before mass production of vehicle ABS, the ABS control strategy needs to be researched and tested in large number. Currently, the main approaches of vehicle ABS testing are road test and static test. Road test is testing ABS performance on roads by assembling ABS on a real vehicle and the performance is tested and assessed through the detection of instrument and the experience of driver. The test results of this kind of method can assess the ABS performance comparatively accurately. However, the cost of test is usually high. Static test is testing ABS performance on test bench, so the requirement of performance of test bench is high [1]. In order to lower the test cost of testing ABS control strategy, it is necessary to develop a test system, which is specifically for ABS control strategy test, to improve the detection and development efficiency of ABS.

To reach the target above, this paper has exploited a simulation test system of ABS performance through Visual C++ and Matlab/Simulink platforms. The functions of this system are imitating variety of vehicles and roads, simulating the braking processes of ABS system and analyzing the processes and results of ABS braking. So the system can test and analyze ABS in the condition of close to the real, and can shorten the development period and cut down the cost.

2. Research of System Development

2.1. System Functions

In accordance with the software engineering approach, it is necessary to plan totally when designing software [2]. The purposes of designing this system is building a platform for ABS mass production, which is used to simulate, test and analyze ABS performance. The system is needed to meet testing function, which means it is needed to provide models of different vehicles and of different roads, to have the modifiability of brake system model to adapt to braking systems of different types or different parameters, to provide import interface of control policy file and to help analyze results of simulation tests. Also the system is needed to run stably, test accurately and prove correct results. Based on the planning above, the specific definition of the system is shown in Figure 1.

a. Function of parameter design and selection. This system stores all needed parameters(including vehicle parameters, road parameters and parameters of transfer function model of braking system) in knowledge base, meanwhile provides parameters directly entry module to assist users call or design relevant parameters.

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b. Function of control strategy input. This system has packaged many logic threshold control methods (including front-wheel simultaneous control, rear-wheel simultaneous control, cross control, four-wheel independent control Etc.), and has provided interfaces to modify thresholds. Users can change control strategy just by selecting control method and modifying threshold of wheel acceleration or slip ratio. If users want to change control strategy at large extent or to add a new control strategy, this system will provide an interface to call Shell Execute () function to run Simulink [3].
c. Function of assisting analyzing. Through calling Matlab engine (introducing file "engine.h"), the simulation test of simulink model is controlled [4] [5]. After the simulation, this system will generate curves and calculation results (including vehicle velocity curve, wheel speed curve, slip ratio curve, brake distance, Yaw rate curve and Yaw angular displacement) automatically, which are used to help analyze, to help tester judge the performance of ABS.
d. Function of storing data and diagram. This system uses test names as non-repeating units providing the data managing function of saving parameters of vehicle, braking system and control strategy and result curves in order to assist ABS series development.

2.2. Testing Process

Process of the test system is shown in Figure 2.

2.3. System Interface

To avoid the tedious situation of manipulating and viewing, which is caused by pop-up dialog of multi-project system, this system uses the user interface used by Maxthon browser and puts a number of functions into many pages through Tab control of Visual C++ to communicate with users layer by layer following the sequence shown in Figure 2. The interface is shown in Figure 3. Under the condition that parameter is missing or is error, the system will pop up message box and not allow testing when pressing the "start test" button. The system also can correct errors automatically, for example the system will delete O and pop up message box when users input letter O as number 0.

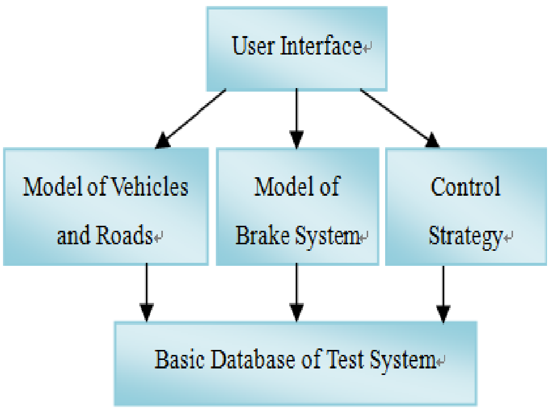


Figure 1. Structure of ABS test system

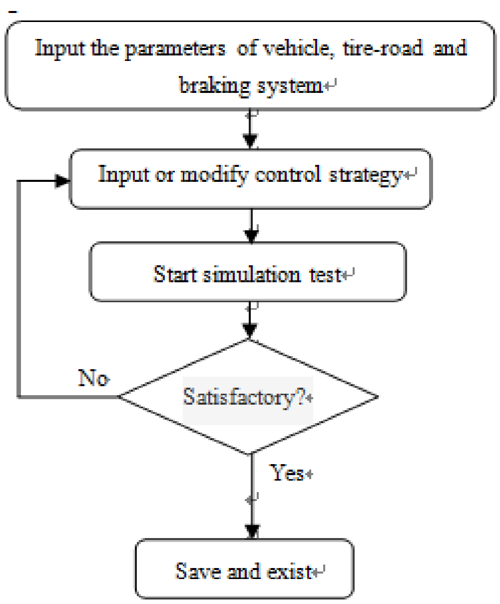


Figure 2. Testing process

3. Build Model

Models of this system mainly include vehicle model [6], engine model, transmission model, wheel model, braking system model and tire-road model.

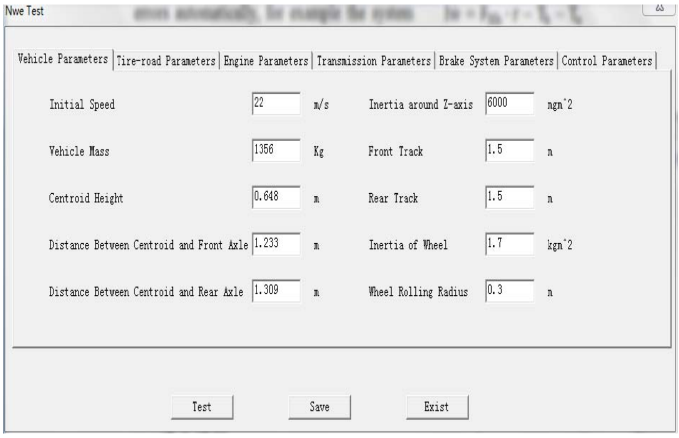


Figure 3. Interface of system

3.1. The Wheel Model with Engine Dragging Torque

Under many emergency braking conditions, drivers have no time to cut the power transmission among engine, transmission system and wheels, especially when the vehicle has manual transmission. Because EFI engine does not inject fuel when the vehicle is braked, it will generate braking torque called engine dragging torque. If the road adhesion situation is good, this torque would not affect ABS greatly, however, if the road adhesion coefficient is low, this torque would cause greatly adverse influence on ABS [7].

The force diagram of a wheel with engine dragging torque is shown in Figure 4.

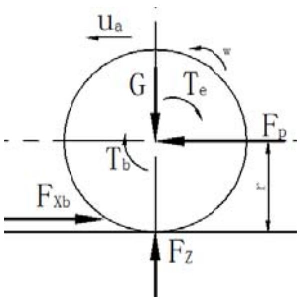


Figure 4. Force diagram of a wheel with engine dragging torque

In Figure 4, u_a is the velocity of wheel centroid, w is wheel angular velocity, r is rolling radius of the wheel, G is vertical load, F_p is the force that vehicle body acts on wheel, F_z is the vertical ground reaction force, F_{Xb} is ground braking force, T_b is the braking torque generated by brake, T_e is the braking torque acting on wheel, which is generated from engine dragging torque and transferred through transmission. So the motion equations of wheel are as:

$$I\dot{w} = F_{Xb} \cdot r - T_b - T_e \quad (1)$$

In the equation, I is wheel rotation inert.

$$T_e = T_{e\_o} \cdot i_g \cdot i_0 \quad (2)$$

In the equation, T_{e_o} is engine dragging torque, i_g is transmission ratio, i_0 is drive ratio. So

$$I\dot{w} = F_{Xb} \cdot r - T_b - T_{e\_o} \cdot i_g \cdot i_0 \quad (3)$$

According to engine character, the relationship between engine dragging torque and rotation speed is shown in Fig.5.

Table 1. The relationship between engine dragging torque and rotation speed.

Rotation speed/r/min	Dragging torque/Nm
600	0
1000	6.3
1400	12
1750	16.5
2100	20
2500	23.5

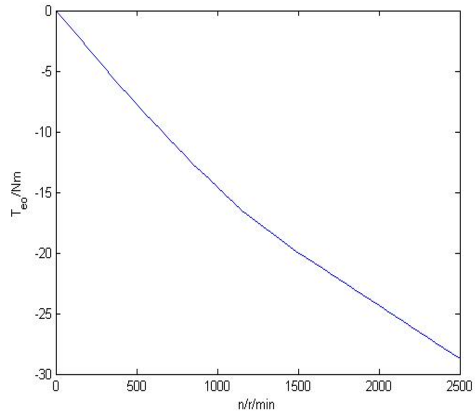


Figure 5. The relationship between engine dragging torque and rotation speed.

The model of engine is simulated by Look-table module. Sampling points of relationship between engine dragging and rotation speed are put into the module directly. So if rotation speed is regarded as input, engine dragging torque would be the output according to Figure 5.

The default sampling data of engine dragging torque and rotation speed is shown in table 1. Users can modify the data in the page of engine model.

3.2. Tire-road Model

The magic formation is used as the mathematical model of tire-road longitudinal force in this system.

$$F_x = F_z \cdot D \cdot \sin(C \cdot \arctan[\{B \cdot s - E \cdot [B \cdot s - \arctan(B \cdot s)]\}]) \tag{4}$$

In the equation, F_x is the ground longitudinal force withstood by tire, F_z is vertical force withstood by tire, s is slip ratio of wheel, B、C、D、E respectively are dimensionless coefficients. The parameters of two kinds of road, which are adopted by this system, are shown in table 2.

Table 2. Road Coefficients

Road	B	C	D	E
Dry asphalt	10	1.9	1	0.97
Snow-ice	5	2	0.3	1

3.3. Brake System Model

In pneumatic or hydraulic braking pipelines of vehicle ABS, pressure regulator regulates pressure in pipelines incessantly, so the dynamic in the pressure transmission process is high. The process of pressure change regulated by ABS is related to brakes, brake master cylinder, pipelines, pressure regulators and wheel cylinders. As many of the parameters are difficult to obtain, the method in reference [8] is adopted, and the direct identification method is used to build the model of transmission characteristics of conduits.

Supposing the transfer function model of braking system is in two-order form with zero and lag, the default pressurization and decompression models of braking system are shown in the following two equations. The model is changed when parameters (including numerator coefficient, denominator coefficients and lag time) that are used to change two-order transfer function have changed.

$$G(s) = \frac{1}{0.0004s^2+0.0556s+1}e^{-0.0165s} \quad (5)$$

$$G(s) = \frac{0.021033s+1}{0.0011s^2+0.0594s+1}e^{-0.0115s} \quad (6)$$

4. Simulation Test of Control Strategy

4.1. Test Purposes

After simulation test of ABS control strategy on different road conditions, curves of vehicle velocity, wheel speed, wheel rotation acceleration and slip ratio, and evaluations of brake time, brake distance, average slip ratio, slip ratio variance, adhesion coefficient utilization and variance of adhesion coefficient utilization can be obtained to assess the performance of ABS [9].

4.2. Basic Conditions of Test

The database of this system can store large number of parameters that are related with testing, so users can select among them or input new data by themselves. The vehicle parameters and others initial conditions are shown in table 3.

Table 3. The relationship between engine dragging torque and rotation speed.

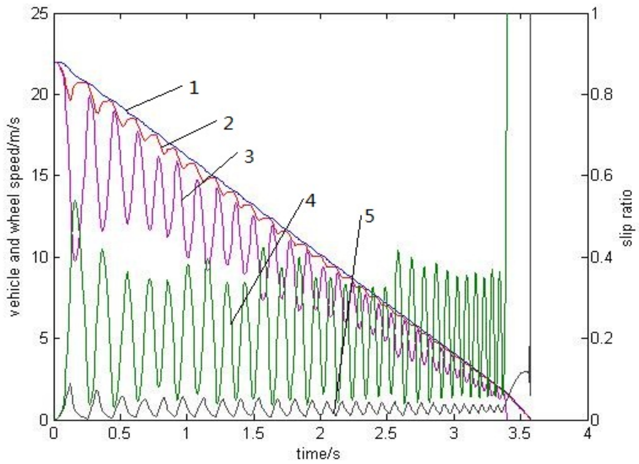
Parameters	Values
Initial Vehicle Speed/m/s	22
Vehicle Mass/kg	1656
Centriod Height/m	0.648
Distance between Centriod and Front Axle/m	1.233
Distance between Centriod and Rear Axle/m	1.309
Yaw Moment of Inertia/kgm^2	6000
Front Track/m	1.5
Rear Track/m	1.5
Wheel Rotating Inertia/kgm^2	1.7
Wheel Rolling Radius/m	0.296

The control strategy used in this paper is logic threshold control method which is widely used in today's ABS. The upper limit threshold and lower limit threshold respectively are 0.15 and 0.2. The vehicle speed of 1.94 m/s (about 7 km/h) is the threshold that used to decide whether to switch on ABS. If vehicle speed is higher than 1.94 m/s, ABS will be switched on. Otherwise, ABS will be turned off. The reference slip ratio used in this control strategy is the biggest one among four slip ratios of four wheels. And the reference vehicle speed is calculated by slope method [10].

4.2. Results of Test on Different Road Conditions

a. Dry Asphalt Road

The result of simulation test on condition of dry asphalt road is shown in figure 6. This test mimics the brake process and brake result of a vehicle when brakes on high adhesion coefficient. As the vertical load on rear axle is less, the slip ratio of rear wheel is relatively larger. And the reference slip ratio in the control strategy is the biggest one among four slip ratios, so the slip ratio of rear wheel is controlled in the range of 0.15~0.2, but the slip ratio of front wheel is about 0.03, which is smaller. Wheels are locked after the vehicle speed is under 7 km/h. And fluctuation in the wheel speed is gentle, the control cycle time is short, and control effect is good. As the road adhesive force provided by dry asphalt road is great, the engine dragging torque contributes little to braking torque, so it influences little to ABS.

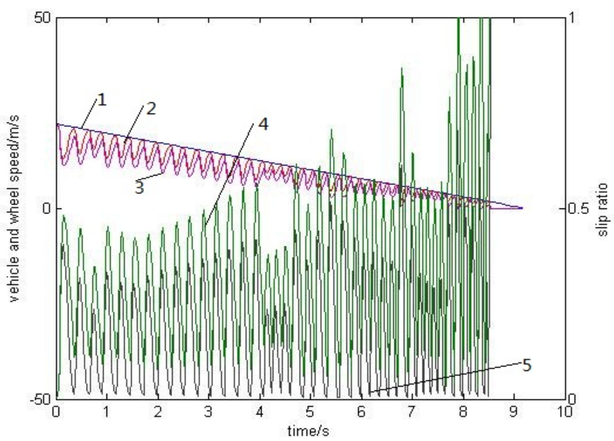


The brake time is 3.38s, the brake distance is 40.84m, the average slip ratio is 0.198, the variance of slip ratio is 0.04532, the average adhesion coefficient utilization is 0.7273, and the variance of adhesion coefficient utilization is 0.02472.
1-vehicle speed curve, 2-front wheel speed curve, 3-rear wheel speed curve, 4-rear slip ratio curve, 5-front slip ratio curve.

Figure 6. The result of test on condition of dry asphalt road.

b. Snow-ice Road

The result of simulation test on condition of snow-ice road is shown in figure 7. The road adhesive coefficient proved by snow-ice road is very low. And the snow will produce a blocking effect on wheels. As the deterioration of road condition, the brake torque that engine dragging torque provides will dramatically increase the possibility of locking wheels. So it raises higher requirements on ABS control strategy. Figure 7 shows that the slip ratio, which is generated by the control policy in this system, is under 0.5. The slip ratio is within the safe range even is bigger than the slip ratio produced on dry asphalt road. And wheels are entirely locked after vehicle speed is under 7 km/h. So the control effect is fairly good.

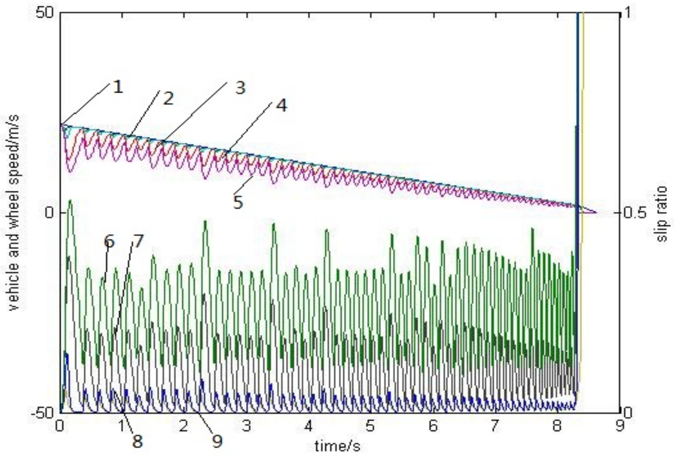


The brake time is 9.167s, the brake distance is 88.6m, the average slip ratio is 0.4, the variance of slip ratio is 0.06187, the average adhesion coefficient utilization is 0.3122, and the variance of adhesion coefficient utilization is 0.005045.
1-vehicle speed curve, 2-front wheel speed curve, 3-rear wheel speed curve, 4-rear slip ratio curve, 5-front slip ratio curve.

Figure 7. The result of test on condition of snow-ice road.

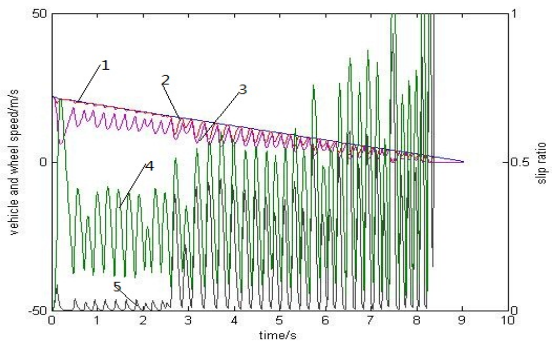
c. Bisectional Road

The simulation result on bisectional road (left wheels are on high adhesion coefficient road, right wheels are on low adhesion coefficient road) is shown in figure 8. As the adhesion conditions are different, the adhesion forces provided by roads are different, so vehicle will deflect to where the adhesion force is greater when braking. The control strategy in this system is equivalent to low-selected control, so it can ensure that the braking forces on both sides of wheels are approaching. The figure 8 manifests that the slip ratio of rear wheel on low adhesion road is about 0.15~0.35, that of front wheel on low adhesion road is about 0.03~0.2 and that of wheels on high adhesion road is about 0.02. This indicates the results achieve the purpose of control policy.



The brake time is 3.38s, the brake distance is 40.84m, the average slip ratio is 0.198, the variance of slip ratio is 0.04532, the average adhesion coefficient utilization is 0.7273, and the variance of adhesion coefficient utilization is 0.02472.
1-vehicle speed curve, 2-left front wheel speed curve, 3-left rear wheel speed curve, 4-right front wheel speed curve, 5-right rear wheel speed curve, 6-right rear slip ratio curve, 7-right front slip ratio curve, 8-left rear slip ratio curve, 9-left front slip ratio curve.

Figure 8. The result of test on condition of bisectional road.



The brake time is 9.014s, the brake distance is 84.61m, the average slip ratio is 0.4238, the variance of slip ratio is 0.07134, the average adhesion coefficient utilization is 0.3122, and the variance of adhesion coefficient utilization is 0.01043.
1-vehicle speed curve 2-front wheel speed curve 3-rear wheel speed curve 4-rear slip ratio curve 5- front slip ratio curve

Figure 9. The result of test on condition of docking road.

d. Docking Road

When a vehicle brakes on docking road, if it is driven from high adhesion road to low adhesion road suddenly, the wheels are so easy to be locked because of reduction of road adhesion. And the braking effect of engine will be intensified if wheel speed is high. So the engine dragging torque will be an important factor to interfere the control process of ABS. This simulation test mimics the situation that a vehicle brakes 2.5s on dry asphalt road then entries on snow-ice road keeping braking. The result is shown in Fig.9. The curves manifest that the slip ratios of front wheels oscillate obviously. The slip ratios are about 0.03~0.4 when these two front wheels are on low adhesion road. The oscillation of rear wheels is increased a little when they move from high adhesion road to low adhesion road. The slip ratios are kept between about 0.11~0.54. These four wheels all are not locked before the vehicle speed is lower than 7 km/h.

5. Conclusion

A simulation test system for testing ABS control strategy is developed based on VC++ and Simulink. This paper has increased the realistic of models and requirement of ABS control policy by building the simulation test model with engine dragging torque. This paper has test ABS on simulation models of four typical roads, and has analyzed and evaluated the test results. So the summary is this ABS simulation test system has user-friendly interface, is easy to modify parameters of models and control strategy, has powerful database support, can mimic so many kinds of roads, and is able to test ABS in the condition of close to the real and is able to help users evaluate the test results.

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