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Vehicle Anti-lock Braking System Performance using dSPACE

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ABSTRACT

As a typical active safety component for automotives, the main goal of the Anti-lock Braking System (ABS) is to prevent wheel lockup and to maintain steerability and stability. This paper focuses on using a model-based approach for developing a mathematical model of ABS. Three different Simulink models are set up for simulation. By using dSAPCE MicroAutoBoxⅡ, the simulation results are listed in this paper.

Keywords: ABS, Automotive, Slip rate, Control algorithm, Vehicle model.

INTRODUCTION

ABS is one of the most important components of modern automotive braking systems which prevents a wheel from becoming fully locked in the vehicle braking process. It is a safety device which is used for improving braking direction stability and steering ability, as well as shortening the braking distance of the vehicle. The main functions of ABS are: (1) to improve the direction stability of the braking vehicle. (2) to ensure that the driver can still control the steering wheel in the braking process, thereby avoiding obstacles. (3) to shorten the braking distance.

dSPACE MicroAutoBox offers a complete and integrated development environment for embedded control software. It is a real-time system for performing fast function prototyping in fullpass and bypass scenarios. It operates without user intervention, just like an ECU. In this project, it works as an ECU for the control algorithm of the ABS system.

THE ABS CONTROL MODEL

As a basic concept, the longitudinal wheel slip ratio S_λ is given by: $S_\lambda = \frac{v-\omega r}{v} * 100\%$, where ω is the wheel angular velocity, r is the wheel rolling radius, and v is the vehicle forward linear velocity. In normal driving conditions, $s=0$, therefore $S_\lambda = 0$. In severe braking, it is common to have $\omega = 0$ while $S_\lambda = 100\%$, which is called wheel lockup. Lockup means the wheel slips on the road without skidding. Wheel lockup is undesirable since it prolongs the stopping distance and causes loss of direction control [1,2]. Normally, the vehicle models which are used include the general vehicle model, the four vehicle model, the half vehicle model and the quarter vehicle model. The one chosen for this research is the quarter vehicle model. The quarter model describes the braking performance, which is suitable for ABS braking performance analysis. On the other hand, it can also simplify the problem.

Figure 1 shows the simplified model of the braking wheel. The dynamic functions of the braking wheel are: $J\omega = F_x \cdot r - T_\mu$ and $F_x = \mu_b \cdot F_z$, where F_x is the longitudinal force, F_z is the normal force, μ_b is the longitudinal friction coefficient, J is the moment of inertia of wheel, r is the rolling radius of wheel, and T_b is the braking torque.

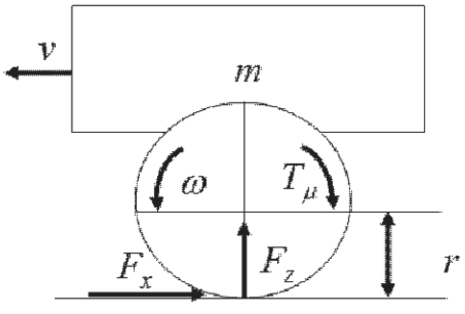


Figure 1 The Simplified Model of the Wheel

The friction behaviour of the wheels can be approximated with parametric characteristics, as shown in Figure 2.

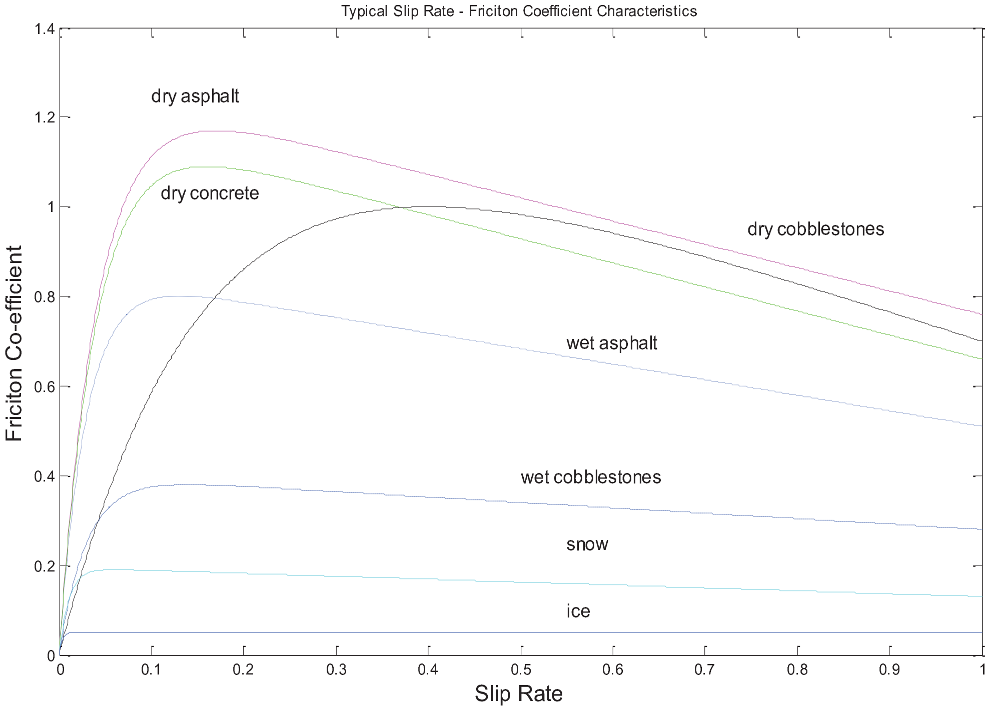


Figure 2 Typical Slip Rate – Friction Coefficient Characteristics

The calculation of the friction forces can be carried out using the method of Burckhardt [3]. The parameters c_1 , c_2 and c_3 are given for various road surfaces in Table 1. The equation using Burckhardt is $S_\lambda = c_1(1-e^{-c2S_\lambda}) - c_3 S_\lambda$. By using the extreme value method, the optimal slip rate and the maximum friction coefficient are: $S_{opt} = \lg(c_1 c_2 / c_3)$ and $\mu_{\max} = c_1 - (1 - \lg c_1 c_2 / c_3) c_3 / c_1$.

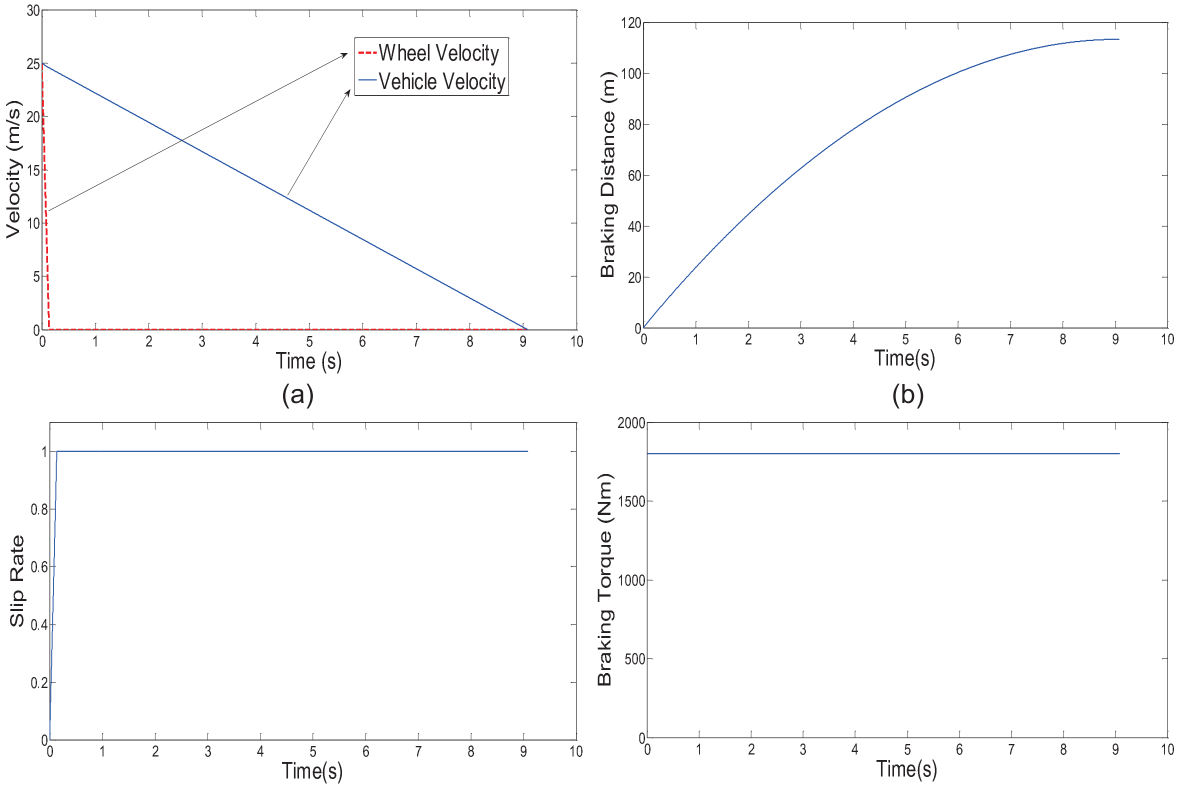
With the exception of wet cobblestones, the Burckhardt characteristics correspond very precisely to the measured characteristics [4]. A measured friction co-efficient characteristic for cobblestones exhibits a higher initial gradient, however this levels out at friction values of about 0.4, and then runs with a smaller gradient to the maximum value, where it can then again be approximated [5].

Table 1 Parameter sets for friction coefficient characteristics (Burckhardt)

Road Type	c_1	c_2	c_3	S_{opt}	$\mu_{\max}$
Asphalt, dry	1.2801	23.99	0.52	0.17	1.1709
Asphalt, wet	0.857	33.822	0.347	0.13	0.8019
Concrete, dry	1.1973	25.168	0.5373	0.16	1.090
Cobblestones, dry	1.3713	6.4565	0.6691	0.15	0.950
Cobblestones, wet	0.4004	33.7080	0.1204	0.14	0.380
Snow	0.1946	94.129	0.0646	0.08	0.190
Ice	0.05	306.39	0.001	0.06	0.050

THE BRAKING SIMULATION WITHOUT ABS

The Simulation model without ABS is shown in Figure 5. With an initial speed $v_0 = 25m/s$ and braking Torque $T_b = 1800Nm$, Figure 3 shows that when a vehicle brakes on a wet asphalt road, the wheel speed reduces sharply, with a zero value in 0.137s, while the slip rate rises synchronously. The wheel is locked up and starts slipping. In this condition, the steering capability and operability is lost totally, which could easily lead to a traffic accident. The braking distance is about 113.3m, with a braking time of 9.087s under the conditions of a wet asphalt road.



(a)

(b)

(c)

(d)

Figure 3 Simulation Result of Hydraulic Pressure Braking without ABS

(a) Vehicle Speed and Wheel Speed in Braking
(b) Distance in Braking
(c) Slip Rate in Braking without ABS
(d) Torque in Braking

THE ABS BRAKING SIMULATION WITHOUT THE PRESSURE-HOLDING PROCESS

The ABS system adjusts the state of the motion of the wheel by controlling the pressure in the brake cylinder. Therefore, study of the influence of hydraulic characteristics is the foundation of research and evaluation of the Anti-lock Braking System. The research into the hydraulic characteristics mainly focuses on the performance in the stages of pressure increase and pressure decrease of the brake cylinders.

In order to develop a model of the ABS hydraulic actuator, we assume that [6]: (1) Ignore the pressure loss because the flow of brake fluid inside the hydraulic pipe is minimal, while the inner side of the hydraulic pipe is smooth enough. (2)Ignore the instant impact of the brake fluid during solenoid valve switching. (3) Ignore the elastic deformation of the braking hydraulic pipe and wheel cylinder body.

When the hydraulic modulator works, assume p_m is the pressure of the master cylinder, while p_w is the pressure of the brake cylinder. In conditions of pressure increase, the brake fluid flows from the master cylinder into the brake cylinder through the apply valve with a liquid flow of $Q = C_T A_T \Delta p_t^k$, where C_T is the flow rate, A_T is the flow area of valve, k is the index of the throttle valve with values from 0.5 to 1.0, $\Delta p_t = p_m - p_w$ is the pressure difference between the front and rear of the throttle valve. When the braking action starts, brake fluid is compressed and the pressure is increased. The continuous flow equation during the pressure increase stage is $Q_w = KV \frac{dp_w}{dt}$, where K is the fluid bulk modulus, and V is the total volume of the brake cylinder and fluid pipes. The pressure change rate of the brake cylinder during the pressure increase stage is $\frac{dp_w}{dt} = \frac{C_T A_T}{KV}(p_m - p_w)^k$.

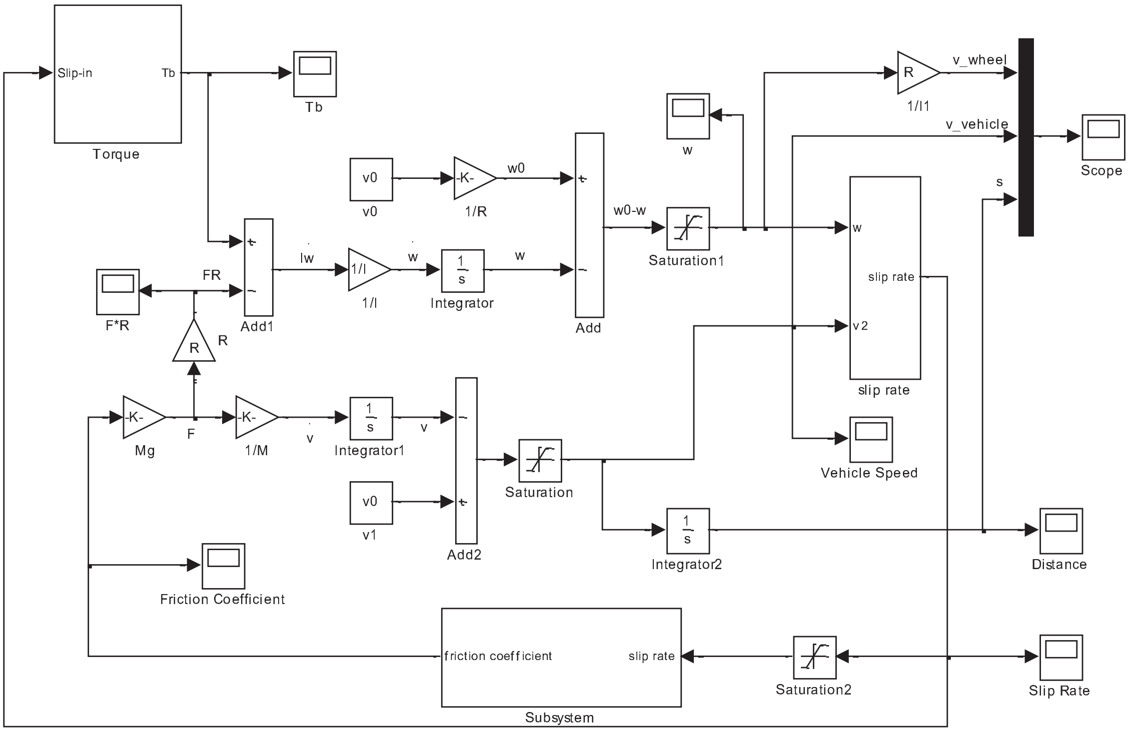
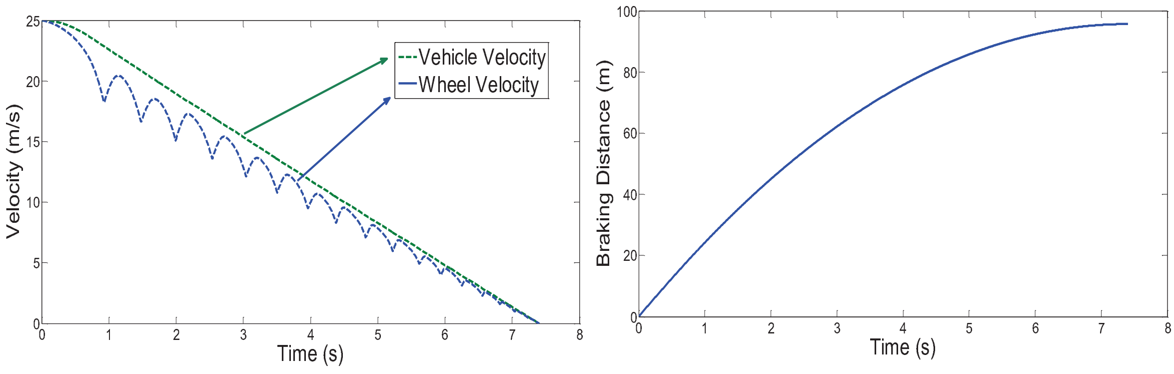
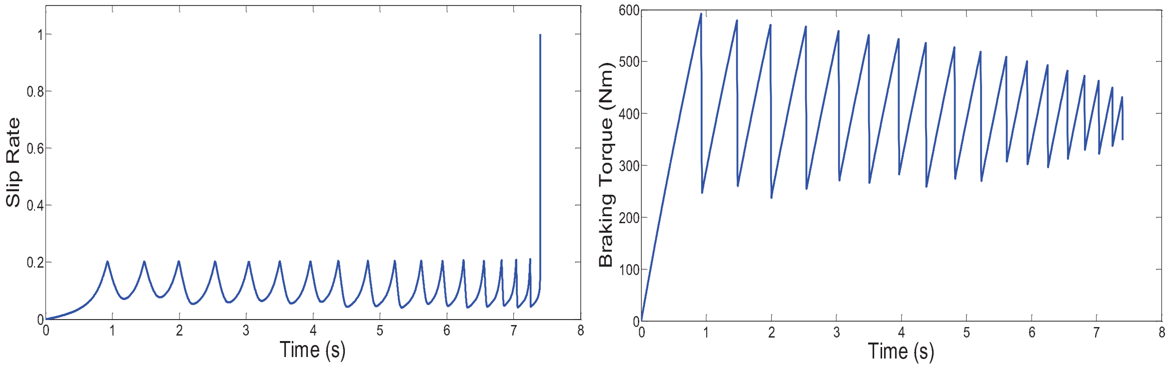


Figure 4 Simulation Model of Logic Control without the Pressure-holding Process

When the pressure decreases, the apply valve is closed, while the release valve is open. Brake fluid inside the brake cylinder flows out into the fluid reservoir. The pressure change rate of the brake cylinder during the pressure decrease stage is $\frac{dp_w}{dt} = \frac{C_B A_B}{KV} p_w{}^{\phi}$, where C_B, A_B and ϕ are the coefficients of the release valve during the pressure decrease stage. A simulation without the pressure-holding process is shown in Figure 4. The subsystem „Torque‟ is receiving the real-time slip rate from the vehicle. The module of the „Switch‟ is set up with a threshold of 0.2, which is called the „Ideal Slip Rate‟. If the real-time slip rate is bigger than the threshold, the switch turns to the pressure decrease module. On the contrary, if the real-time slip rate is less than the threshold, the switch turns to the pressure increase module. Figure 5 shows the simulation results of the ABS without the pressure-holding progress with an initial brake torque of 1800Nm and an initial vehicle velocity of 25m/s. The wheel is not locked during the entire braking process. The braking distance is about 95.66m, with a braking time of 7.402s. The biggest value braking torque is about 600Nm and the smallest value is about 250Nm.



(a) (b)



(c) (d)

Figure 5 Simulation Result of Logic Control without the Pressure-holding Process

(a) Velocity under Logic Control (c) Slip Rate under Logic Control

(b) Braking Distance under Logic Control (d) Braking Torque under Logic Control

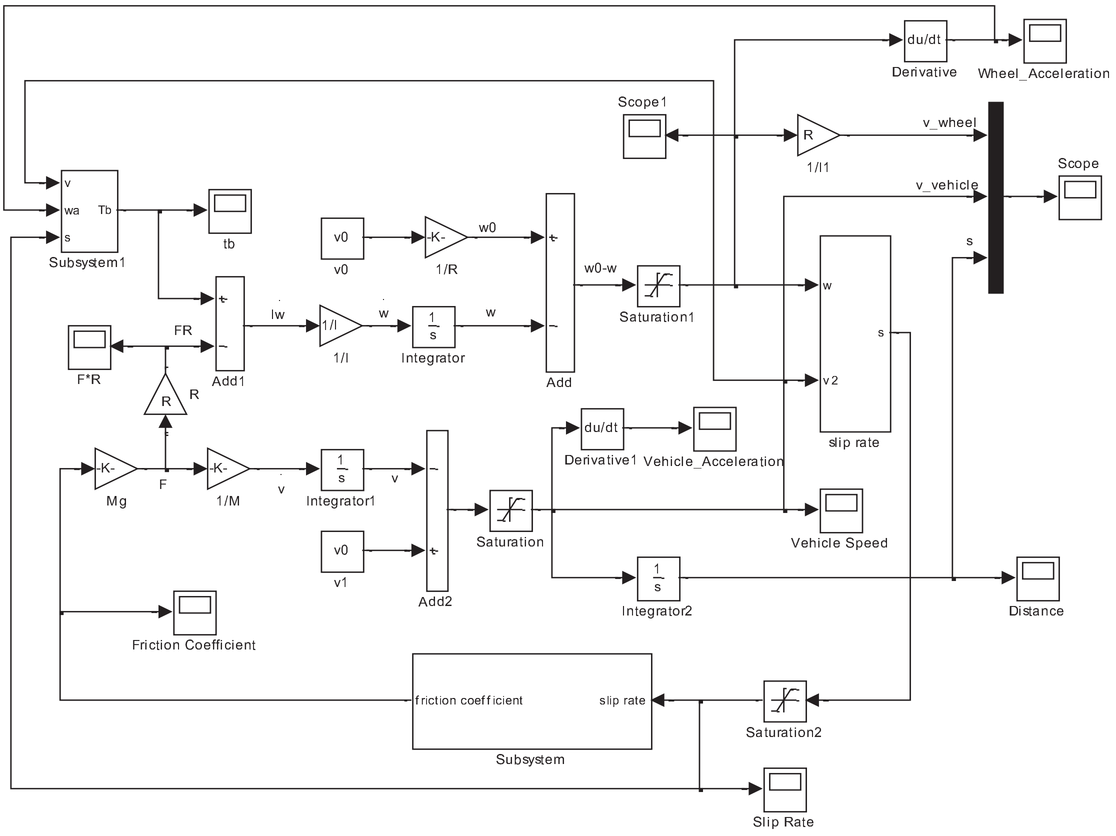


Figure 6 Simulation Model of Logic Control with the Pressure-holding Process

THE ABS BRAKING SIMULATION WITH THE PRESSURE-HOLDING PROCESS

In the pressure holding stage, the braking pressure is not changed with $\frac{dp_w}{dt} = 0$. According to the experimental data, the characteristic model of the hydraulic throttle system can be identified as

$$\begin{cases} 37.2162(p_m - p_w)^{0.54} & Pressure\_Increase \\ 0 & Pressure\_holding \\ -35.5261 p_w^{0.95} & Pressure\_Decreasing \end{cases}$$

[6]. The brake torque $T_b = K_{pb} p_w$, where K_{pb} is

braking efficacy coefficient. The simulation model of the ABS with the pressure holding progress is shown in Figure 6.

The simulation results are shown in Figure 7 with an initial braking torque of 500Nm and an initial vehicle velocity of 80m/s on wet cobblestones road.

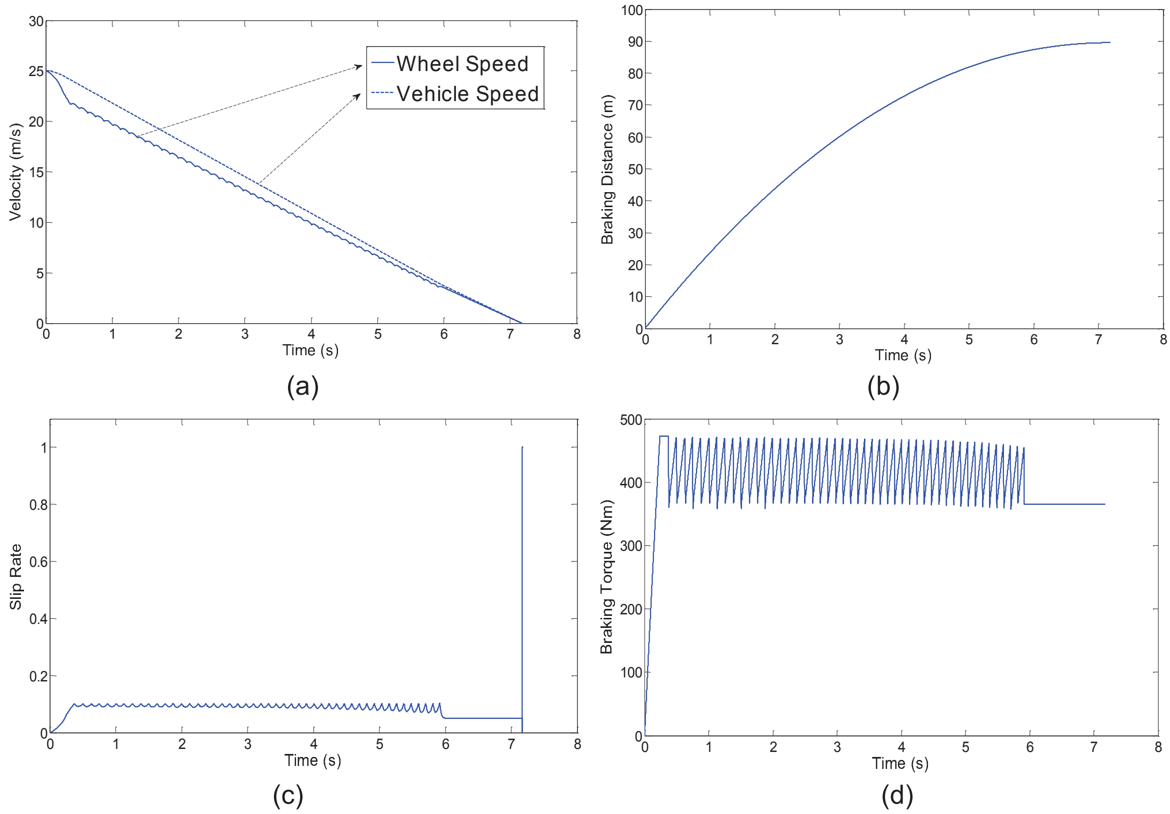


Figure 7 Simulation Result of Logic Control with Pressure-holding Process
(a) Velocity under Logic Control (c) Slip Rate under Logic Control
(b) Braking Distance under Logic Control (d) Braking Torque under Logic Control

CONCLUSIONS

In this paper, the simulation model of ABS is developed which takes fully into account the dynamic model of the vehicle, the mechanical model of the wheel and the model of the hydraulic braking system. In order to unify the feasibility and reliability of the simulation, a quarter vehicle model is a good choice. By comparing the simulation results of velocity, braking distance, slip rate and braking torque between no ABS, ABS without the pressure holding progress and ABS with the pressure holding progress, it can be seen that the brake distance and vehicle stop time is reduced step by step. The Anti-lock Braking System can work efficiently on automotives during braking. The model of ABS in this paper can be applied to road tests of future work.

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