Simulation of the integrated controller of the anti-lock braking system

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Abstract–This paper presents simulation of integrated controller of vehicle anti-lock braking system, which consists of the traditional continuous PID and finite state machine theory. Based on the integrated controller, slip ratio and deceleration are selected as the main control parameters to optimize ABS. Vehicle speed, wheel speed, braking distance, pressure state and slip ratio are investigate to reveal the performance of anti-lock braking system. Single-wheel system is studied in this paper to prove that the controller can effectively reduce braking distance and time and also can improve the stability of anti-lock braking system, which can provide a guideline to the design of anti-lock braking system.

Keywords–Anti-lock braking system; integrated controller system; simulation.

I. INTRODUCTION

Anti-lock braking system is an important development in vehicle safety in recent years. When an emergency occurs, ABS can prevent the wheels from skidding and obtain a stable braking system. Lots of researchers have investigated ABS through various control strategies in recent years, for example PID control[1], wheel-slip peak localization[2,3], Wheel angular acceleration calculation[4,5], fuzzy control[6-8], neural network control[9]. Generally, the major difficulty involved in the design of a vehicle control system is that the performance depends strongly on the knowledge of the tire/road characteristic. This characteristic depends on the wheel slip as well as road condition [2]. The slip ratio is defined different on the road conditions. For most of the traction control design the slip ratio as the controlled parameter, for its direct influence on the braking force.

Since ABS is a system combing continuous slip changing and discrete valve action which induces discrete hydraulic pressure, PID and finite state machine theory are applied to the anti-lock braking system. In the strategy proposed here, PID controller is applied in slip-peak location and finite state machine theory is to limit the acceleration of the vehicle [10]. The object of this is to obtain a desired braking force and to maintain adequate stability. Both of the controllers are simple and can effectively reduce the braking distance and braking time and stabilize the system.

Single-wheel system is simulated and analyzed as follows，different controller and road conditions are studied and reveal that the integrated controller can improve the performance of vehicle braking system.

II. SINGLE-WHEEL VEHICLE MODEL

The single-wheel model of the vehicle on hill road dynamics mode is shown as Fig.1, where the wind force, hill climbing force and rolling resistance are neglected. The slip ratio s is defined as the relative difference of the vehicle velocity and the wheel velocity, $s = \dfrac{v - v_\omega}{v}$ (1).

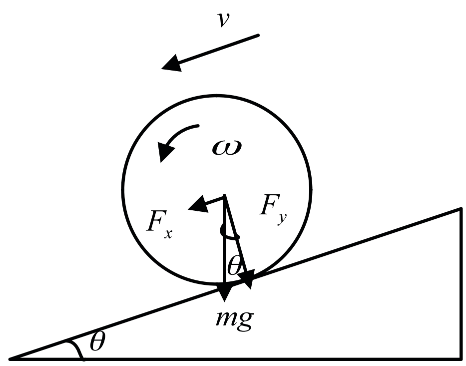


Fig. 1 single-wheel on hill road dynamics mode

Where v, v_ω are vehicle velocity and wheel velocity, it can be expressed as $v_\omega = \omega r$ (2)

where ω is the wheel angular velocity and r the radius of wheel.

When the road condition is downhill, the motion equation of the wheel is $J_\omega \dfrac{d\omega}{dt} = -T_m + r(F_y(s) + F_x)$ (3)

where J_ω is the wheel inertia and T_m is the braking torque.

When the car uphill, the motion equation of the wheel is

$$J_\omega \frac{d\omega}{dt} = -T_m + r(F_y(s) - F_x) \quad (4)$$

where $F_y(s) = \mu(s) mg\cos\theta$ (5)

$$F_x = mg\sin\theta \quad (6)$$

where m is the vehicle weight and g is the gravitation acceleration. And $\mu(s)$ is the adhesive coefficient between the road surface and the tire. It's a function of slip ratio s.

III. CONTROL ALGORITHM

In general case of the anti-lock braking system, the strategy of control consists to keep up the slip ratio around 18-22%.In this study, the vehicle traction control consists to design a control law in order to optimize the braking force. This optimization consists to maximize the tire forces whatever the conditions of the road. Therefore, it must to localize the wheel slip ratio which corresponds to the peak tire road adhesion characteristic. the location and the value of these peak values varies in large range depending on the road, tire and many other different factors, For any rolling conditions, the optimal wheel slip rate, which will be used as control reference to optimize the braking force. The anti-lock braking system proposed here, consists of an integrated controller. One is PID controller and one is based on finite state machine theory. Since the anti-lock braking system consists hydraulic adjusting action, which is mechanical part, finite state machine theory is applied to simplify the logic operation. In this part, deceleration is the main control parameter of the system; the control algorithm is shown in Table 2. The slip ratio is still the main control parameter of the PID control, and is regulated in 20%, which is relative peak adhesive coefficient slip ratio as shown in Table 1. The parameters of the braking system are shown in Table3.

Table1. Slip ratio is the parameter of control block

Vehicle speed	Slip ratio	Braking pressure
V>=15km	>=0.22	Pressure down
	>=0.18 and<0.22	Pressure keep
	<0.18	Pressure up
V<15km	-	Pressure up

Table2. Deceleration and slip ratio are the parameters of control block

Deceleration /acceleration speed	Slip ratio	Braking pressure
-20=<A<20m/s2	<=0.2	Pressure up
A<-20m/s2	<=0.2	Pressure up
	>0.2	Pressure down
-20=<A<20m/s2	>0.2	Pressure keep
A>20m/s2	-	Pressure up

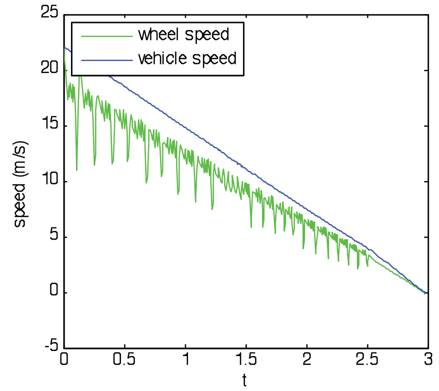
Table3. The parameters of the braking system

parameters	value	parameters	value
gravitation acceleration	9.8m/s^2	peak adhesion coefficient	0.9
road gradient	0.15	peak adhesion coefficient slip ratio	0.2
wheel moment of inertia	9.55 kg m^2	adhesion coefficient at wheel locked	0.65
1/4 vehicle mass	300 kg	Deceleration speed limit	-20 m/s^2
wheel rolling radius	0.3 m	Acceleration speed limit	20 m/s^2

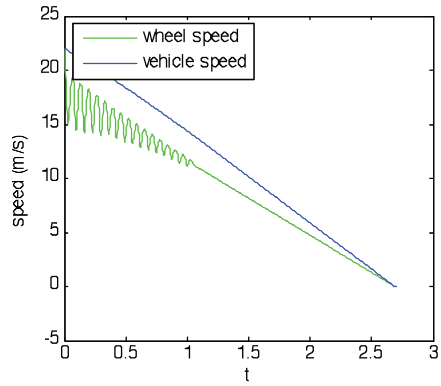
IV. SIMULATION AND ANALYSIS

The longitudinal characteristics are studied of the integrated controller anti-lock brake system. In order to optimize the braking force, it is necessary to locate the slip ratio which corresponds to the peak tire road adhesion characteristic. Vehicle speed, wheel speed, braking distance, pressure state and slip ratio are the principal investigation to reveal anti-lock brake system.

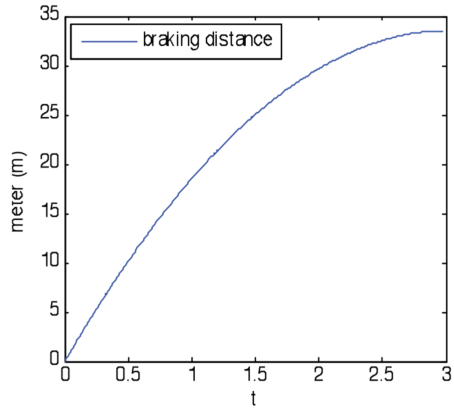
In this study, the anti-lock braking system consists of the design of control law in order to obtain an optimized braking force. Different controller is built to investigate the braking system, which is shown in Table 1 and Table2. The control strategy shown in Table 1 is to keep the slip ratio around 18%-22%, the control strategy proposed here is to limit deceleration speed between +20 m/s2 and -20m/s2 as shown in Table2, and the vehicle slip ratio is regulated in 20%. The corresponding simulation results are shown in Fig.2. The parameters of the braking system are listed in Table3. We can set different road condition and initial velocity to study the braking characterizes in different conditions. The simulation result has been shown as following Fig.2.



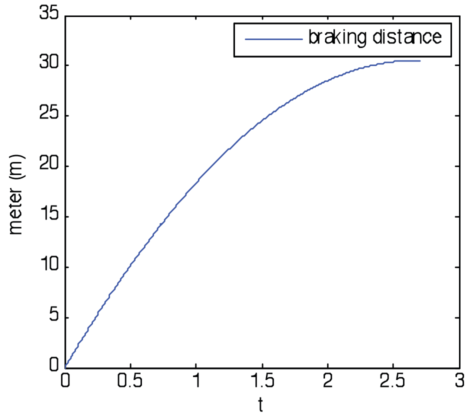
(a) Wheel speed and vehicle speed when slip ratio is the control parameter



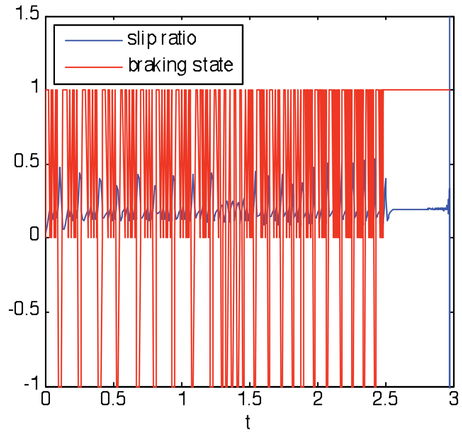
(b) Wheel speed and vehicle speed when integrated controller is applied



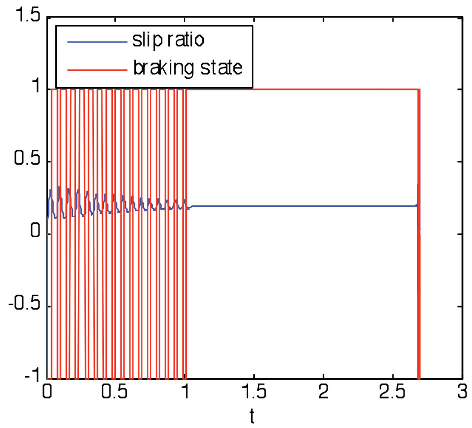
(c) Braking distance when slip ratio is the control parameter



(d) Braking distance when integrated controller is applied



(e) Pressure state and slip ratio when slip ratio is the control parameter



(f) Pressure state and slip ratio when integrated controller is applied

Fig. 2 Simulation results of slip ratio (left) selected as control parameters and integrated controller applied (right).

Fig.2 shows the information of the braking characterizes of the anti-lock brake system. These ABS controllers are simulated in dry concrete road surface. In Fig. 2 (a) (c) (e), the slip ratio is kept from 18% to 22%. In Fig.2 (b) (d) (f), deceleration speed limits are -20 m/s2 and 20 m/s2 and slip ratio is kept around 20%. As we can see in Fig. 2 (a) and (b), which is wheel speed and vehicle speed. It is obvious that the braking time is about 0.25s longer when we just use slip ratio as the control parameter which is also obviously shown in Fig. 2 (c) and (d). The braking distance is shown in Fig. 2 (c) is about 3 meters far than Fig. 2 (d). This is the most important key in the braking system. The controller output is converted into on-keep–off commands by the PWM scheme to control the solenoids in ABS module. Fig. 2 (e) and (d) is solenoid state and slip ratio of the braking system respectively. We can clearly see that the operation of the braking system. And the duration of continuing pressure-up state of the left system is about 1.5 s longer than that of the right system.

V. Conclusion

In this simulation study, two strategies are investigated to obtain an optimized braking force under the condition of the dry concrete road. The simulation results reveal that the system with integrated controller can effectively reduce braking distance and braking time, which can provide a guideline to the design of anti-lock braking system.

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