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Professional paper

Antilock Braking System

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Abstract

Antilock Braking System (ABS) is an automobile safety system. Antilock braking systems are used in modern cars to prevent the wheels from locking after brakes are applied. The vehicle is provided with the controller to control the necessary torque to maintain optimum slip ration. The dynamics of the controller needed for antilock braking system depends on various factors. It's an automated system that run on principles of threshold braking and cadence braking which were practiced by skillful drivers with previous generation braking system. Its response time is faster hence that makes it easy steering for the driver. The vehicle model often is in nonlinear form. Controller needs to provide a controlled torque necessary to maintain optimum value of the wheel slip ratio. ABS generally offer advanced vehicle control and minimize the stopping distance. The slip ratio is represented in terms of vehicle speed and wheel rotation.
In present work first of all system dynamic equations are explained and a slip ratio is expressed in terms of system variables namely vehicle linear velocity and angular velocity of the wheel. By applying a bias braking force system, response is obtained using Simulink models. Using the linear control strategies like P - type, PD - type, PI - type, PID - type the effectiveness of maintaining desired slip ratio is tested. It is always observed that a steady state error of 10% occurring in all the control system models.

Keywords: Antilock Braking system, controller, stopping distance, slip ratio.

Introduction

Anti-lock braking systems (ABS) prevent brakes from locking during braking. Under normal braking conditions, the driver controls the brakes. However, during severe braking or slippery roads when the driver causes the wheel to approach the lock, the anti-lock system takes over. ABS modulates the brake line pressure independent of the pedal force to bring the wheel speed to the level of the level of breakdown required for optimum braking performance. An anti-lock system consists of wheel speed sensors, a hydraulic modulator and an electronic control unit. The ABS has a retraction control system that modulates the braking pressure in response to the wheel deceleration and angular velocity of the wheels to prevent the lock of the controlled wheel. The system closes when the vehicle speed is below a predetermined threshold.

Objective

During the design of ABS, nonlinear vehicle dynamics and unknown environment characters as well as parameters, change due to mechanical wear have to be considered. PID controller are very easy to understand and easy to implement. However, PID loop require continuous monitoring and adjustments. In this line there is a scope to understand improved PID controllers with mathematical models. The present work, it is planned to understand and obtain the dynamic solution of quarter car vehicle model to obtain the time varying vehicle velocity and wheel. After identification of system dynamics, a slip factor defined at each instance of time will be modified to desired value by means of a control scheme. Various feedback control schemes can be used for this purpose. Simulation are carried out to achieve a desired slip factor with control scheme such as

4) Proportional Integral Derivative Feedback Control - PID

Graphs of linear velocity, stopping distance and slip ratio for system is plotted and compared with each other. At the end, possible alternate solutions are discussed. The work is inspired from the demo model of ABS provided in Simulink software.

Vehicle dynamics

Basically, a complete vehicle model that includes all relevant characteristics of the vehicle is too complicated for use in the control system design. Therefore, for simplification a model capturing the essential features of the vehicle system has to be employed for the controller design. The design considered here belongs to a quarter vehicle model as shown in Fig. 1. This model has been already used to design the controller for ABS.

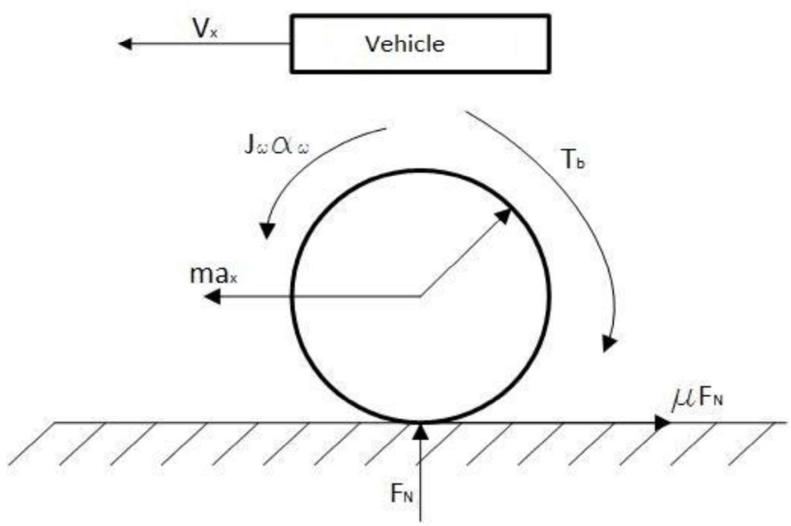

Figure 1. Quarter vehicle model

The longitudinal velocity of the vehicle and the rotational speed of the wheel constitute the degrees of freedom for this model. The governing two equations for the motions of the vehicle model are as follows:

For braking force balance in longitudinal direction (vehicle)

$$ma_x = -\mu F_N \Rightarrow \ m\frac{dv_x}{dt} = -\mu F_N \tag{1}$$

Summing torque at wheel centre (wheel)

$$J_\omega a_\omega = \mu R F_N - T_b \Rightarrow J_\omega \dot{\omega} = \mu R F_N - T_b \tag{2}$$

For convenience a slip ratio is defined according to:

$$\lambda = \frac{v_x - \omega R}{v_x} \tag{3}$$

Differentiating on both sides with respect to time (t), we get

$$\dot{\lambda} = \frac{\dot{v}_x(1-\lambda) - \dot{\omega} R}{v_x} \tag{4}$$

Vx	= linear velocity of vehicle
a_x	= linear acceleration of vehicle
ω	= rotational speed of wheel
α_ω	= angular acceleration of wheel
Tb	= braking torque
λ	= slip ratio
μ	= friction coefficient
R	= radius of tire
m	= mass of the model

Problem formulation

The relation of the frictional coefficient versus wheel slip ratio provides the explanation of the ability of the ABS to maintain vehicle steer ability and stability, and still produce shorter stopping distances than those of locked wheel stop. The friction coefficient can vary in a very wide range, depending on factors like:

(a) Road surface conditions (dry or wet),
(b) Tire side-slip angle,
(c) Tire brand (summer tire, winter tire),
(d) Vehicle speed, and
(e) The slip ratio between the tire and the road.

Friction model is used here. It gives value of coefficient of friction as a function of linear velocity and slip ratio.

$$\mu(\lambda, v_x) = \left[c_1\left(1 - e^{-C_2\lambda}\right) - c_3\lambda\right]e^{-C_4 v_x} \tag{5}$$

Where

C1 is the maximum value of friction curve;
C2 the friction curve shapes;
C3 the friction curve difference between the maximum value and the value at $\lambda = 1$; and
C4 is the wetness characteristic value. It lies in the range 0.02–0.04s/m.

Where for dry asphalt as the surface conditions, above parameters are

C1= 1.2801, C2 = 23.99, C3=0.52, C4= .03

The effective coefficient of friction between the tire and the road has an optimum value at particular value of wheel slip ratio. This value differs according to the road type. From Fig. 2 it is clear that, for almost all road surfaces the frictional coefficient value is optimum when the wheel slip ratio is approximately 0.2 and worst when the wheel slip ratio is 1 in other words when wheel is locked. So, objective of ABS controller is to regulate the wheel slip ratio (λ) to target value of 0.2 to maximize the frictional coefficient (μ) for any given road surface.

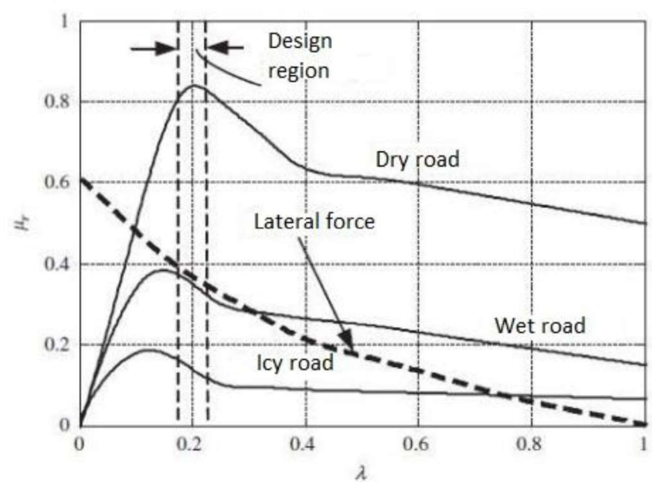

Figure 2. Frictional coefficient of road surface v/s wheel slip ratio

Simulink model of quarter vehicle

In order to model the ABS with different controller's system incorporating the dynamic equations is modeled in Simulink environment. Fig. 3 shows the block diagram of the Simulink model representing vehicle dynamics during straight line braking.

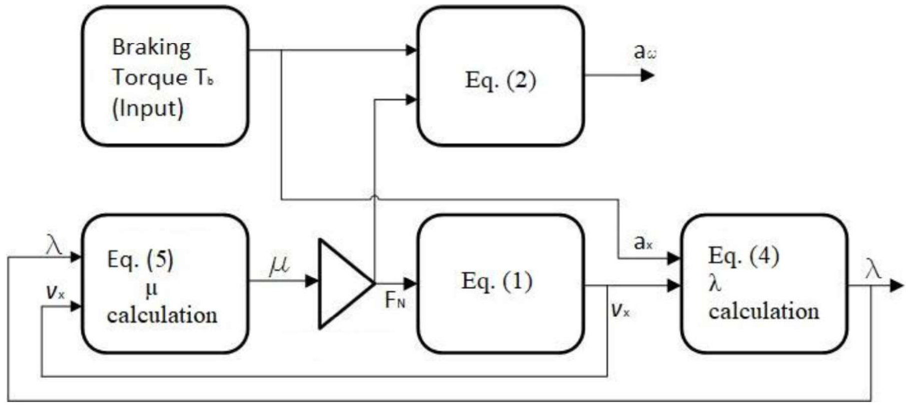

Figure 3. Block diagram representing dynamics of equations

After modeling equations into Simulink model, we get complete Simulink model of quarter vehicle during straight line braking without feedback control as shown in Fig. 4.

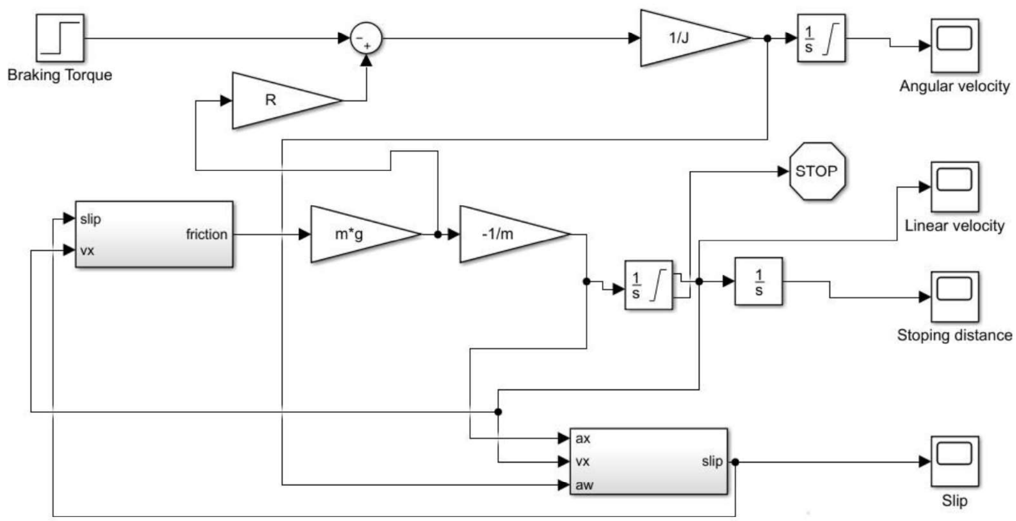

Figure 4. Vehicle model without feedback control

Simulink model of ABS using PID feedback control

Simulink model shown in Fig. 4 is modified to use it as a system subgroup in modeling of feedback control system. Fig. 5 shows the modified version in which a SUM box is added between input terminal (which is control torque u) and brake torque Tb. So the total torque input T to wheel is

$$T = u + Tb \qquad (6)$$

This subgroup formed is shown in Fig. 6

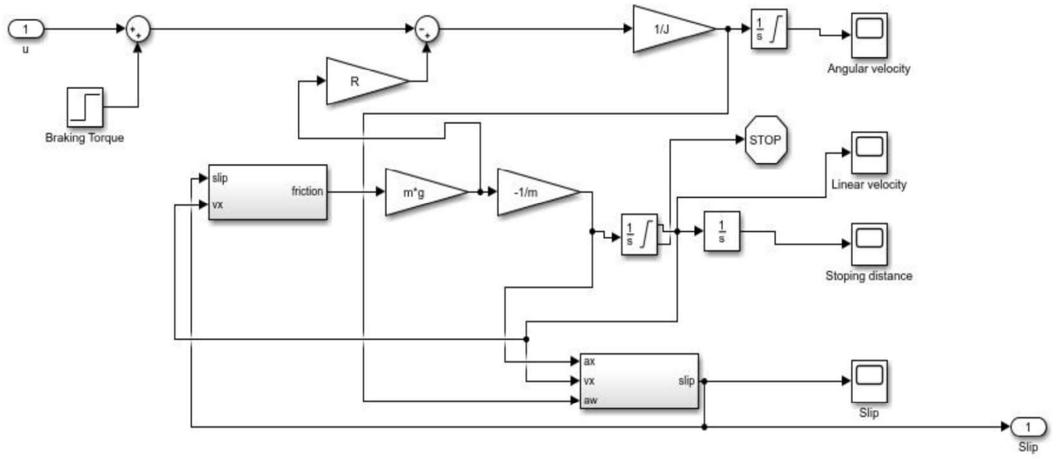

Figure 5. Modified vehicle model without feedback control

Figure 6. Subgroup of System

PID- type control system where Kp is proportional gain, Kd is differential gain and Ki is integral gain are used, is shown in Fig. 7.

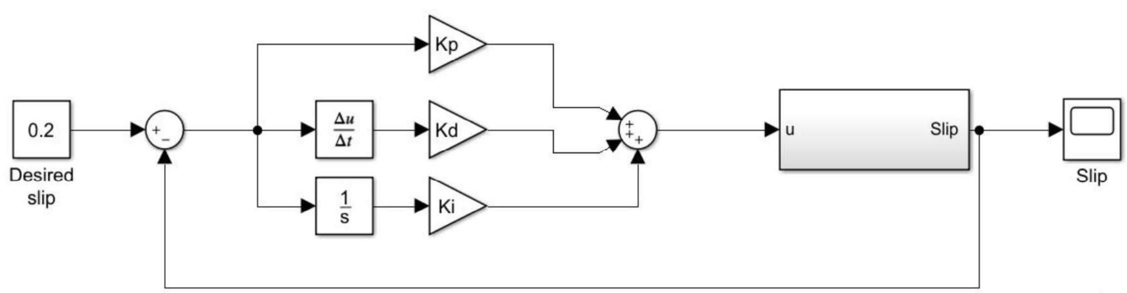

Figure 7. PID feedback control

Results and discussion

This chapter describes the controlled slip response outputs using linear control models.

Input parameters used

To simulate the performance of different vehicle parameters with and without any feedback control system under straight line braking following input parameters are considered.

R=0.4 m,
m =480 kg,
Jw =1.13 kgm^2,
g =9.81 m/s^2,
Max braking torque = 1700Nm
Initial linear velocity = 27.78m/s = 100 km/h
Initial rotational speed = 84.18 rad/s
λd = 0.2
Kp = 300
Kd = 7
Ki = 20

Straight line braking of vehicle without feedback

Fig. 8 shows the behavior of vehicle parameters during straight line braking without any controller. Fig. 8 a, b, c and d are plot of vehicle angular velocity, vehicle linear velocity, slip ratio, and stopping distance respectively versus time.

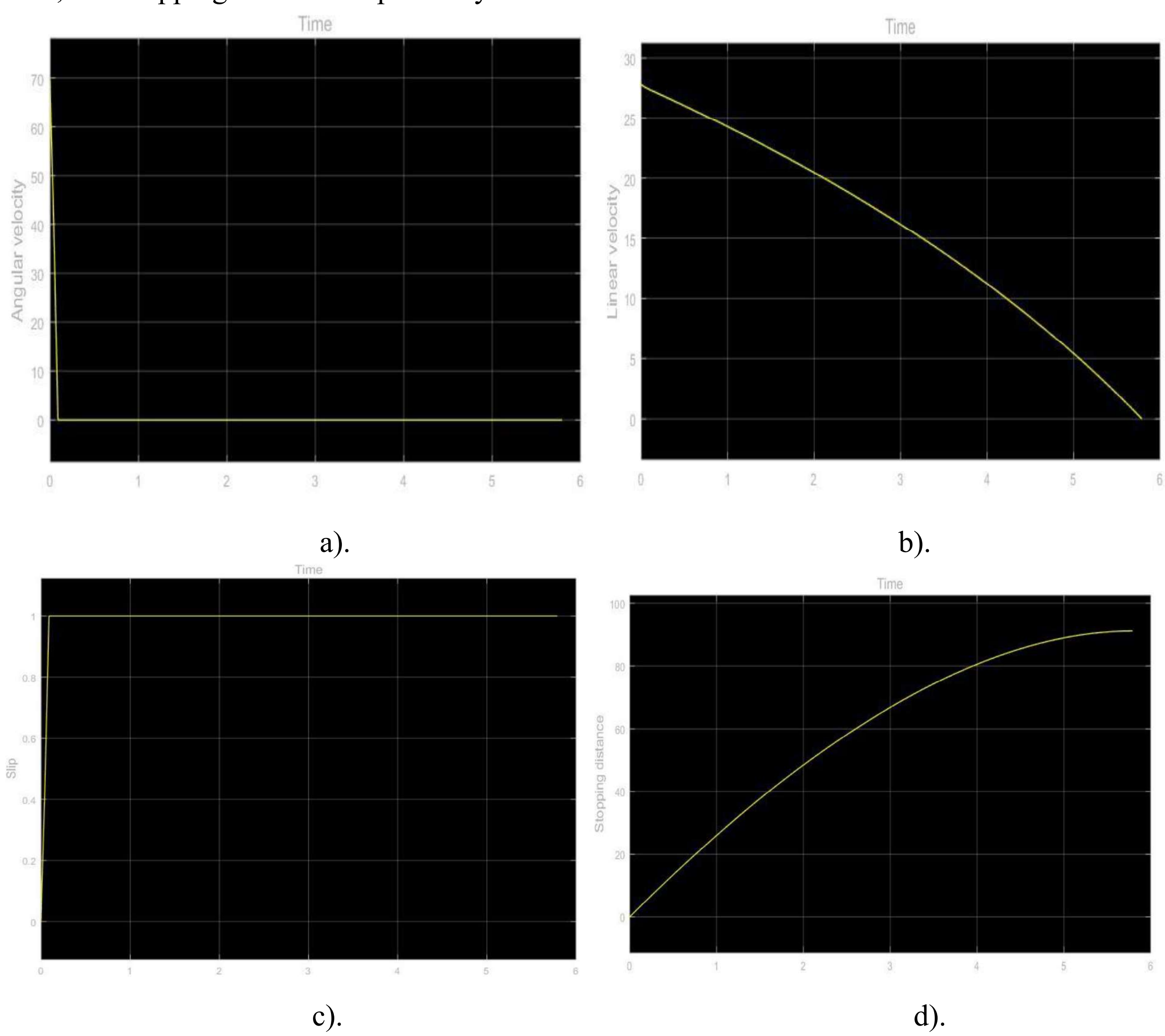

Figure 8. a) wheel angular speed; b) linear velocity; c) slip; d) stopping distance

It is seen that slip ratio has been varying from 0 to 1 from application of brakes to the wheel stopping instant. Even the wheel speed is zero at .1 seconds, the stopping distance of 91 m occurs at 5.8 seconds. This indicates that wheel has been locked before vehicle comes to halt. That means during braking steer ability is lost at .1 seconds due to locking of wheel.

Proportional integral derivative control – PID

Similarly, in case of PID type feedback control plots of slip ratio versus time and stopping distance versus time are obtained.
Fig. 9 shows the behavior of vehicle parameters during straight line braking with PID controller. Fig. 9 a, b, c and d are plot of vehicle angular velocity, vehicle linear velocity, slip ratio, and stopping distance respectively versus time.

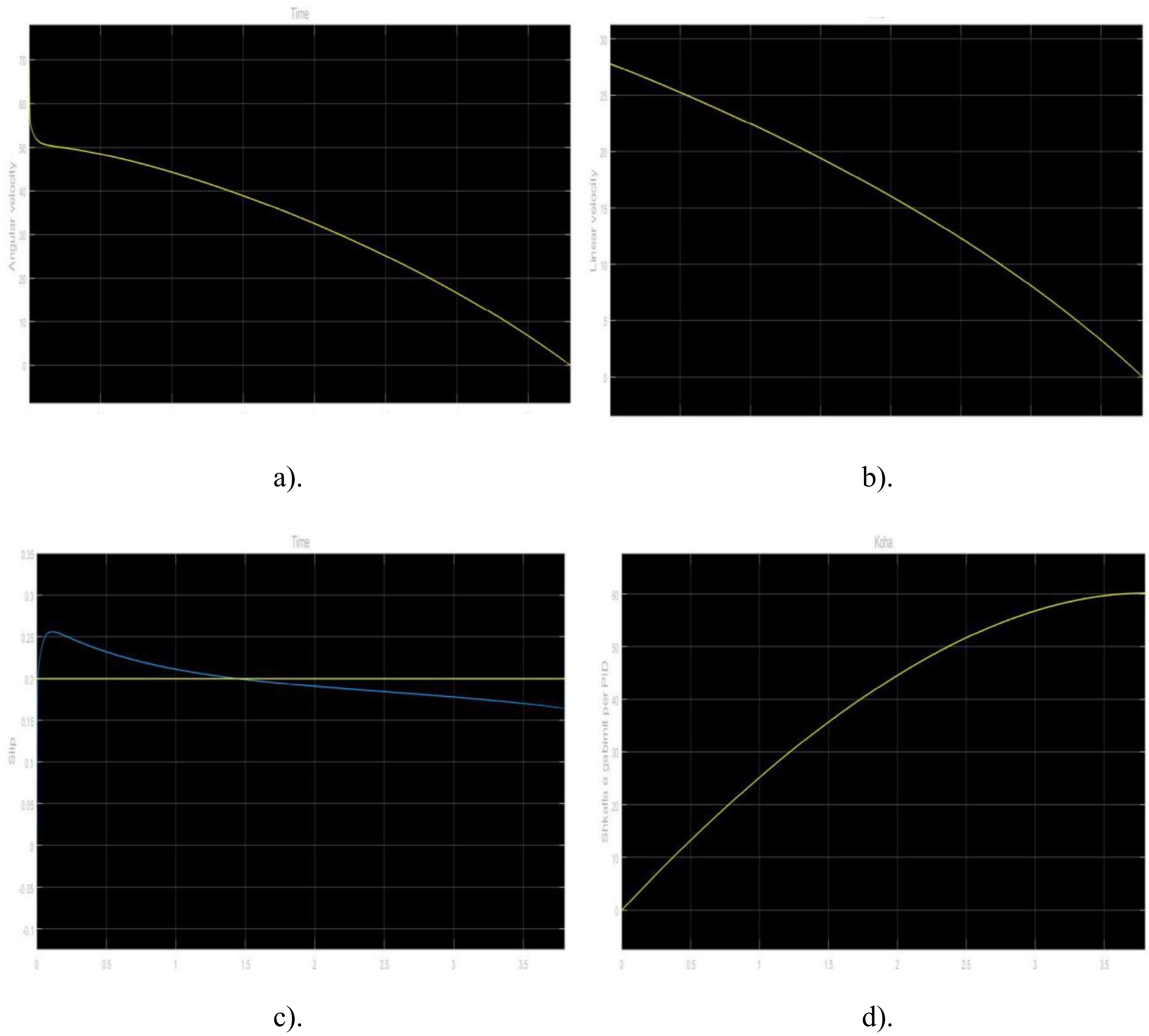

Figure 9. a) wheel angular speed; b) linear velocity; c) slip; d) stopping distance

It is seen that the slip value is reached at desired value 0.2. Time and stopping distance are decreased considerably. Wheel speed is zero when linear velocity and stopping distance are zero. This means that wheel is not blocked before when vehicle is stopped.

Discussion

It is clear that ABS improves braking performance of vehicle. Comparing slip ratio v/s time graphs of different control schemes suggests that a proportional controller (Kp) will have the effect of reducing the rise time and will reduce but never eliminate the steady-state error. An integral control (Ki) will have the effect of eliminating the steady state error, but it may make the transient response worse. A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response.

Table 1. Braking performance results

ABS	Stopping time	Stopping distance
Braking without controller	5.8s	91m
PID-type	3.8s	60m

Conclusion

In this paper an attempt is made to understand the application of various type of linear controller used for antilock braking systems. The system was modeled with a quarter vehicle dynamics and differential equation of motion was formulated. The slip ratio is used control as a criterion for this control work. Friction force and normal reaction are function of slip ratio and in turn entire equations were nonlinear. The time histories of the wheel, stopping distance of the vehicle, and slip factor variation are obtained for benchmark problem available in literature. Like PID-type have been implemented to augment the constant braking torque so as to control the slip ratio.

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