Linear PID Control Technique for Single Wheel ABS (Anti-lock Braking System) of Motorcycle

Harshal Rameshwar More
Department of Instrumentation and Control
(M Tech. Process Instrumentation)
College of Engineering, Pune
Pune, India
harshal.more307@gmail.com

Aniket Ashokrao Digrase
Department of Instrumentation and Control
(M Tech. Process Instrumentation)
College of Engineering, Pune
Pune, India
digrase.aniket@gmail.com

Arjun Vasant Wayse
Department of Instrumentation and Control
(M Tech. Process Instrumentation)
College of Engineering, Pune
Pune, India
waysearjun7265@gmail.com

***Abstract* — automotive safety applications become more and more common in today's Cars, Trucks and also in Motorcycles. Vehicle stabilization systems such anti-lock braking systems (ABS) and electronic stability control are introduced since the late 1970's and have now become almost standard in every passenger car. ABS are mainly applied to two track vehicles, i.e. which have at least four wheels. For single-track (two-wheeled) vehicles such as motorcycles, because the realization of applications is more challenging due to the extended system dynamics and practical limitations such as space, weight, power requirements, etc.**

In this work elaborative study of motorcycle ABS system is given. The aim of this paper is to design linear PID controller and obtained desired braking performance in order to prevent wheel locking of considering motorcycle wheel dimensions. The performance of the proposed controller is verified in MATLAB/ Simulink environment.

Index Terms— ABS (Antilock Brake System), ECU (Electronic control unit), CBS (Combined braking system), MU (Modulator Unit)

I. INTRODUCTION

Desire for improvements in safety is more paramount with Motor cycles in comparison with car because of grave nature of consequences in accidental situations. The percentage of motorcycle traffic deaths among the total number of traffic deaths is comparatively high when the number of miles driven is taken into consideration. A report of the European Transport Safety council showed that riding a motorcycle is 20 times more dangerous than driving a car at the same distance. The Insurance Institute for Highway Safety (IIHS) conducted a survey on the ABS effectiveness for motorcycle and came to the conclusion that motorcycles above 250cc without ABS are 37% more likely involved in fatal motorcycle accidents and this can be reduce by using motorcycle ABS. The results of this survey led European Union commission to initiate a legislative process and which resulted into mandatory ABS for motorcycles above 125 cc becoming from 2016 onwards. As per the notification issued by the Indian Government in August 2015, had made CBS mandatory for two-wheelers at or below 125cc and ABS for two-wheelers above 125cc by April 2019.

There is a lot of advancement in ABS systems for cars, trucks and other heavy vehicle but when it comes to the single track vehicle like motorcycle and bicycle it is still in nascent stage. The most crucial point is highly nonlinear vehicle dynamics and how to deal with it in order to achieve system robustness. Other things are like size constraint, cost and power requirements etc.

Basically there are two types of control variables as,

1. Wheel deceleration control:

The amount of wheel deceleration depends on road surface so measurement or estimation of road surface is required. It is difficult to obtain set point which may lacks controller robustness. Measurement of only wheel speed is required.

2. Wheel slip control:

Easy to obtained set point for all type of road surfaces. This makes controller very robust as estimation of road surface is not required. Measurement of both wheel speed and vehicle speed are required.

The slip ratio control is most widely used and accepted. The slip ratio is derived by S = (Motorcycle velocity-wheel velocity)/Motorcycle velocity. The Pacejka research [4] shows that the when the slip ratio is in between 10-30% then the lateral and longitudinal friction coefficient are at its peak value for different types of road surfaces .On the basis of this research slip ratio in this work is taken as 0.2.

In [1] M. Shamsmohamadi designed a motorcycle ABS pilot model which shows that the stoppage time for the new ABS is about 40% less than that is the non-ABS type. Chun-Kuei Haung [2] has given sliding mode based hydraulic antilock braking system for a motorcycle and verified via HIL simulation. Many researchers are using quarter wheel models such as [4] Adarsh Patil uses uncertainty estimation approach on Inteco model. In [7] Mirzaeinejad and Mirzaei has design a non-linear model based controller for the wheel slip control. The integral feedback technique is also employed to increase the robustness of the designed controller. Ruled based control is also used by some researcher which has threshold value of slip and braking torque.

II. DESCRIPTION OF ABS SYSTEM

ABS is an electronic vehicle safety system which monitors and control wheel slip during vehicle braking and helps to improves stopping distance. When brakes are applied the vehicle and wheel speed start decreasing. However, the decrease in vehicle speed is not always corresponding to the decrease in wheel speed.

The non-correspondence between wheel speed and vehicle speed is called slip and its magnitude is represented by slip ratio (λ),

$$\lambda = \frac{Vx - R\omega}{Vx} * 100$$

Where,
V_x -Vehicle Speed
R- Radius of wheel
ω - Angular speed of wheel

ABS System consist of following subsystem

- Wheel Speed Sensor
- ECU
- Hydraulic Pressure Modulator

In advanced ABS system other inputs like roll angle sensor, gyroscope sensors, acceleration sensor are used to realize advanced feature like HSA (Hill start assist), Curve traction control, cornering ABS, lateral stability control etc.

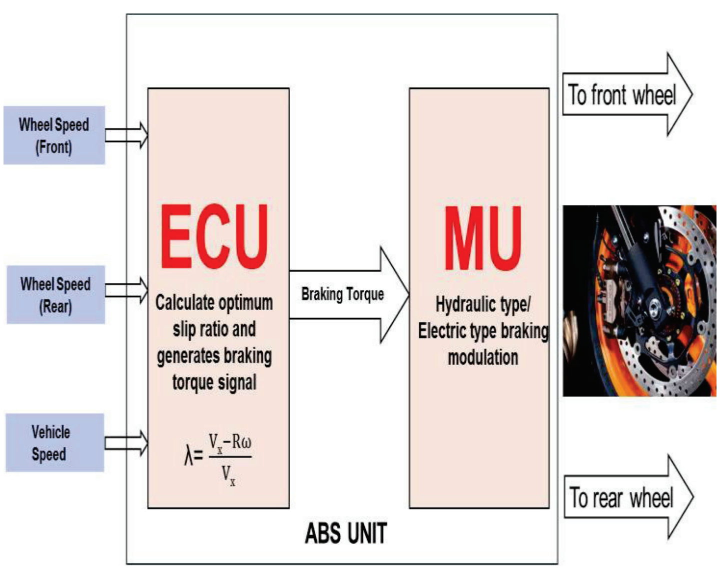

Fig.1 ABS system components

A . Wheel Speed Sensor

In case of two channels ABS system two wheel sensors are used i.e. front wheel and rear wheel. This wheel sensor continuously monitors wheel speed and it detects the rapid vehicle deceleration. These sensors are mounted near a rotating disc or in some cases toothed rings are used for Electro-magnetic or Hall-effect type pulse pickups and mounted directly on the rotating components of the wheel hubs. In some ABS cases, vehicle speed is estimated from wheel speed by using estimation algorithm like Kaman's filtering, observer designing etc. Otherwise accelerometer is also used by some manufacturer.

B. Electronic control unit (ECU)

From fig [1], it is cleared that output of wheel speed sensors is given as input to the ECU which then calculate slip ratio and generate optimum braking torque in order to prevent wheel locking condition. The operation like slip comparison and velocity estimation are performed in ECU. The generated output signal is given to the hydraulic pressure modulator.

C. Hydraulic Pressure modulator

The hydraulic pressure modulator is an electro-hydraulic device for pressure modulation i.e. reducing, holding and building pressure. It consists of electromagnetic solenoid valves, pump motor, pressure sensors and accumulator. The ECU output signal actuates the solenoid valves and motor in order to achieve targeted pressure as the pressure sensor measures a pressure inside calipers.

III. MATHEMATICAL MODELLING AND MATLAB SIMULATION OF ABS USING SINGLE WHEEL MODEL

A. Goals

- To design PID controller to minimize the difference between vehicle speed and wheel speed during deceleration cycle and achieve reference slip ratio for dry and asphalt type of road conditions
- To ensure minimum braking distance and time

B. Vehicle Dynamics

Basically, a complete motorcycle model that includes all longitudinal and lateral dynamics is too complicated to use in the control system design. Therefore, for simplification a single wheel model capturing all the essential features of the motorcycle wheel has been taken into consideration. The design considered here belongs to a single wheel of motorcycle as shown in fig.2 The longitudinal velocity of the motorcycle and the rotational speed of the wheel constitute the degrees of freedom for this model.

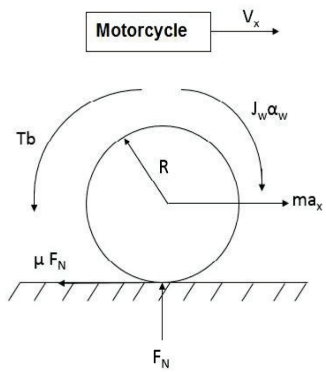

Fig.2 Single wheel of motorcycle model

According to Newton's second law of motion from Fig. 2 the longitudinal force is given by,

$$F_x = ma_x \qquad \text{----------------- (1)}$$

The equations for this motion are given by,

$$ma_x = -\mu F_N \qquad \text{----------------- (2)}$$

$$J_\omega \acute{\omega} = \mu R F_N - T_b \qquad \text{----------------- (3)}$$

Thus, the states of the model can be determined as,

$$V_x = \frac{-\mu F_N}{m} \qquad \text{----------------- (4)}$$

$$\acute{\omega} = \frac{\mu R F_N - Tb}{J\omega} \qquad \text{----------------- (5)}$$

For convenience a slip ratio is defined according to:

$$\lambda = \frac{Vx - R\omega}{\max(Vx, R\omega)} \qquad \text{----------------- (6)}$$

C. Tire road friction model

In present work, Burkhardt's tire road friction model [6] is used. It gives value of coefficient of friction as a function of linear velocity and slip ratio.

$$(\lambda, Vx) = [C_1 (1 - e^{-C_2\lambda}) - C_3\lambda] - e^{-C_4 Vx}$$

Where, for dry asphalt as the surface condition then above parameters are,

$c_1 = 1.28$, $c_2 = 23.9$, $c_3 = 0.51$, $c_4 = 0\ .03$

The tire-road friction coefficient has an optimum value at particular value of slip ratio. This value varies according to the road conditions. From fig.3 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 desired value of 0.2 to maximize the frictional coefficient (μ) for any type of road surface.

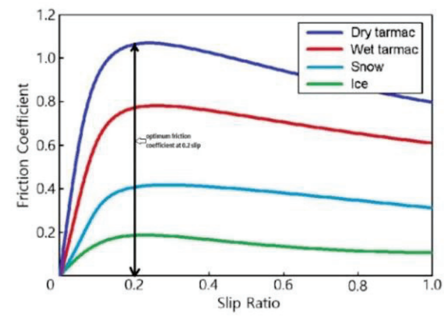

Fig.3 Slip ratio v/s friction coefficient for different road profiles

Table.1 Parameters of ABS system

Name	Description	Units
V_x	Linear speed of motorcycle	(m/sec)
ω	Angular speed of wheel	(rad/sec)
R	Wheel radius	(m)
T_b	Braking torque	(Nm)
m	Mass of the rider and motorcycle	(Kg)
J_ω	Wheel moment of inertia	(kgm^2)
μ	Friction coefficient	-
λ	Slip ratio	-

D. Matlab/Simulink Simulation

In order to prevent wheel locking condition we have taken λ=0.2 as a reference value. In this paper we simulate the wheel and vehicle dynamics in open loop and closed loop control. In open loop there is no slip regulation i.e. normal braking condition which can be called as non-ABS case and in case of close loop we fed slip through unity feedback gain and designed PID to achieve reference slip ratio and this can be called as ABS.

To simulate the given system, following input parameters are considered.

R=0.33 m,

m =210 kg,

J_ω= 1.1 kgm^2,

g =9.81 m/s^2,

Maximum braking torque = 1500 Nm

Initial linear velocity of a motorcycle=27.78 m/sec

Initial angular velocity of wheel=84.14 rad/sec

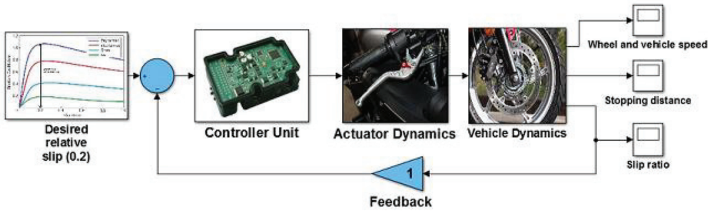

Fig.4 Matlab/Simulink model

D.1. Controller Unit

This unit consist of PID controller in which K_p =250, K_i=10 and K_d =5. The error from comparator is given to the control unit and corresponding braking torque is generated.

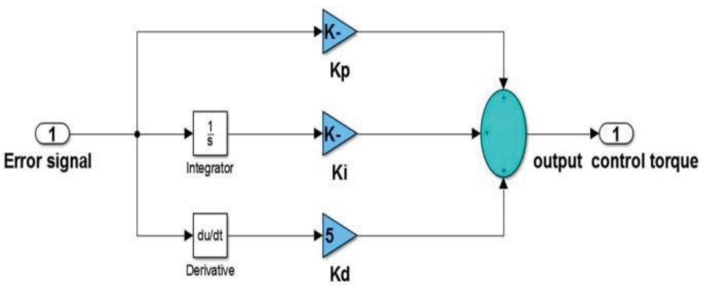

Fig.5 PID Controller

D.2. Actuator Unit

This unit consists of actuator behavior with Bang-bang action and hydraulic lag with 1500 Nm. as a maximum braking torque as shown in fig.6.

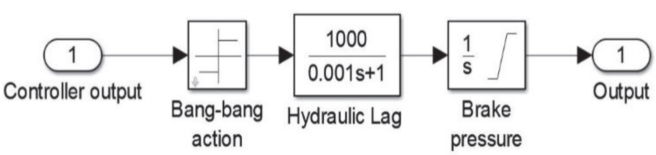

Fig.6 Actuator Unit

In real time ABS system the wheel speed from sensors is fed back to the comparator continuously and ECU monitors a locking conditions. As there will be rapid wheel deceleration, the ECU generates optimum braking torque signal and it is given to the hydraulic modulator which will actuates solenoid valves and prevents wheel locking.

In the given work, simple closed loop feedback control using PID is design for the ABS case. In non-ABS case feedback and PID controller are removed which resulted into wheel locking as shown in section IV.

E. Simulation Results

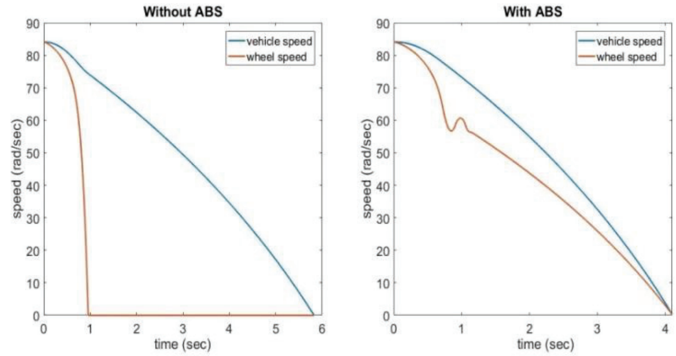

Fig.7 Wheel and Vehicle Speed with and without ABS

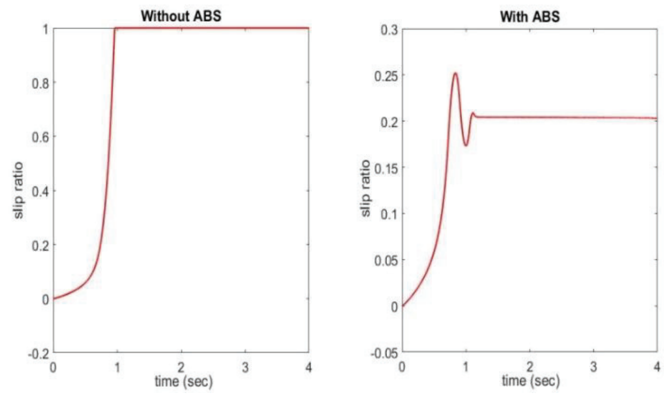

Fig.8 Slip ratio with and without ABS

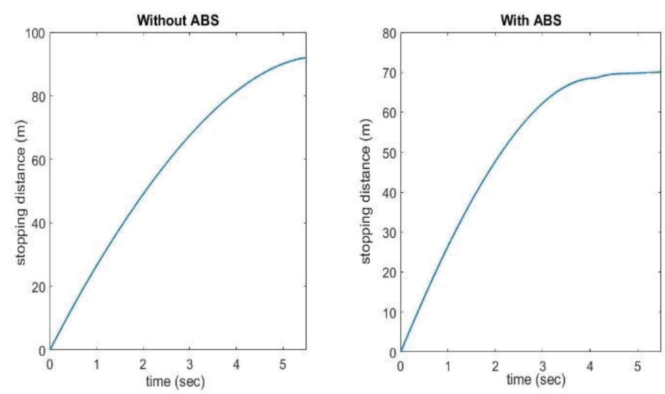

Fig.9 stopping distance with and without ABS

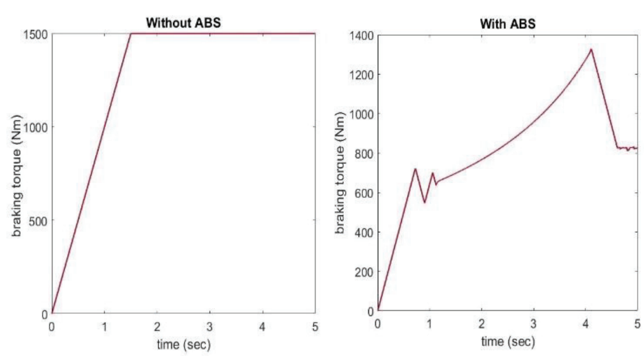

Fig.10 Braking torque with and without

IV. CONCLUSION

In the present work, it was main attempt to understand real time ABS system for motorcycle. The system was modeled with single wheel dynamics and equation of motion was formulated. The slip ratio is used as a controlled variable for this control work. Nonlinear tire road friction model which is a function of slip ratio and normal force is used. Basic linear PID controller is designed which generates optimum braking torque signal and desired slip is achieved. The given results show improvements in stopping distance as compared to non-ABS system.

V. FUTURE SCOPE

In this paper only single wheel dynamics are considered in future to make system practically more realizable full longitudinal dynamics of bike can be taken. In such model there may be variation of center of gravity or there may be addition of some uncertainty and disturbances. In case of such highly non-linear model the given linear PID cannot withstand. To deal with such system intelligent controller like Sliding mode controller, Adaptive controller, Neuro-fuzzy controller etc. can be designed.

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