Modelling and Comparative Analysis of Anti-Lock Braking System (ABS) Control Strategies for Motorcycle Based on MATLAB/Simulink

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Abstract— As the dependency of Electronic content is increasing in the automobile sector for safety purpose and performance requirements. For safety considerations, ABS (Anti-Lock Braking System) is an active feature for most of the vehicles. ABS is mainly used to stop vehicle without wheel locking and decreases stopping distance with minimum time period. ABS System having an ECU (Electronic control Unit) which maintain the slip on the basis of wheel and vehicle dynamics and control the fluid pressure in brake calliper for effective braking. This paper mainly focuses on modelling and simulation based control methodology using half wheel model of vehicle. Simulation model contains a vehicle dynamics model, wheel dynamics model, slip model, sliding mode optimizer and brake actuator model which all makes close loop feedback control system which increases braking performance of the motorcycle. PID controller including with sliding mode optimizer controls longitudinal slip, brake torque and stopping distance of the motorcycle. Comparison results of the motorcycle without ABS control system and with ABS control system are generated using MATLAB/Simulink platform.

Key words: Anti-Lock Braking System (ABS), MATLAB/Simulink

I. Introduction

In the era of the 21st Century, the importance of time, speed along with active safety is the most required feature in the rapid development of automobile industries. ABS (Anti-Lock Braking System) is one of the active features used for efficient braking in terms of stopping distance and control of the vehicle during braking, thus ABS is an essential component which requires in every vehicle. Some more following reasons are as well to equip the ABS in Vehicles:

1) Electronics system growth rate in the Automotive sector.
2) Strict implementation of ABS system by Government on motorcycle reaching 120 kmph,
3) High starting torque and more acceleration are required low braking distance & high traction control.

A modern ABS (Anti-Lock Braking System) is fully based on electronics closed-loop control systems which ultimately increases braking performance with dry as well as wet or slippery surfaces. ABS also maintain slip which increases driving stability and reduce braking distance. According to the principle of ABS, the Best braking effect can be achieved by maintaining the slip from 0.15 to 0.25.

Anti-lock Braking System consists of a controller, speed sensors, Hydraulic Solenoid Valves, oil tank, and check valves etc. Speed sensors give the wheel speed and vehicle speed to the controller. The controller controls the solenoid valve actuation on the basis readings given by wheel speed and Vehicle speed sensors. The Controller controls the brake pressures valve's opening and closing to maintain the required slip.

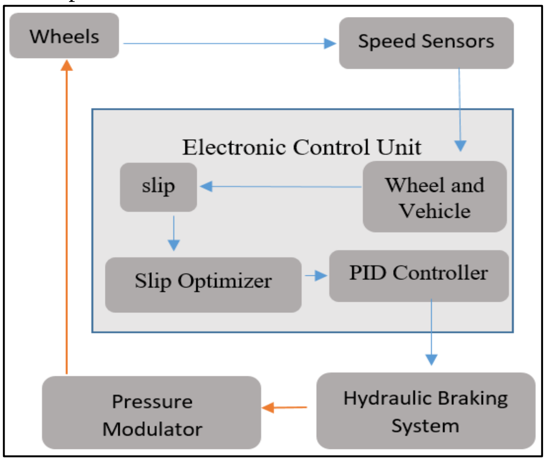


Fig.1: Block Diagram of ABS System

In this paper, an ABS Simulation model is developed with MATLAB Simulink platform. In the model, a PID controller is used to optimize the brake pressure to maintain the slip during braking. PID loop controller requires continuous adjustment with monitoring. The developed Simulation model of ABS is optimized to get better and stable results. Simulink model is tested at different speeds of the vehicle and the outcomes are shown in the graph as well as in tables form.

II. System Modelling:

A. Vehicle dynamics model:

Vehicle dynamics model is very useful for the evaluation of braking performance. So, for better evaluation consider single wheel model. The dynamics of a single wheel is detailed here.

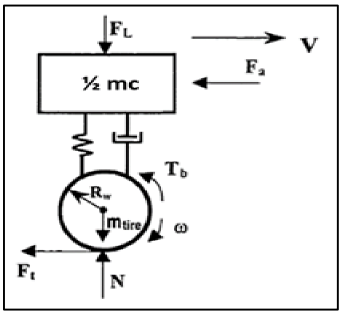


Fig.2: Vehicle Dynamics Model

In this single wheel model rolling resistance force is very small because of braking so it can be neglected.

As per as newton's second law of motion:

$$m_t * a = -F_t - F_a \quad (2.1)$$

Where V=Vehicle Velocity,

F_t=Road friction force,

F_a=Aerodynamic force acting on a vehicle,

m_t=total mass transfer of half vehicle.

Road friction can be expressed as:

$$F_t = \mu N \quad (2.2)$$

Where N=Total normal load,
μ=Road adhesion coefficient,
The total mass of single wheel can be expressed:

$$m_t = m_{tire} + 1/2(m_c) \quad (2.3)$$

Where m_{tire} = Tire mass,
m_c = Vehicle mass
The total normal load can be expressed by:

$$N = m_t * g - F_L \quad (2.4)$$

Where $F_L = \frac{m_c h_c}{2L} * a$
= Longitudinal weight transfer,
h_c = Center of gravity height,
L= Wheel Base
The Aerodynamic force acting on the motorcycle:

$$F_a = \frac{1}{2}\left(\frac{\rho}{2} C_d A_F V^2\right) \quad (2.5)$$

Where ρ = mass density of air,
C_d = Vehicle drag coefficient,
$A_F = 1.6 + 0.00056(m_c - 765)$
= Vehicle frontal area**,**

This mathematical equation can be represented in Matlab Simulink as follows:

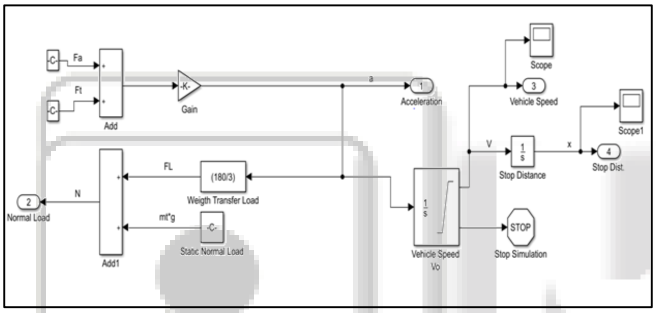


Fig.3: Simulation Model of Vehicle Dynamics

B. *Wheel Dynamics Model:*

While braking stopping torque applied to the wheel, wheel speed decreases and vehicle speed also decreases. As per as Newton's second law of motion at wheel DOF can be given by following equation.

$$J_w \omega = (-T_b + F_t R_w) \quad (2.6)$$

Where J_W= Wheel moment of inertia,
ω = Wheel Speed,
R_W = Wheel Radius,
T_b = Braking Torque,
F_t = Road friction force

This mathematical equation can be represented in Matlab Simulink as follows:

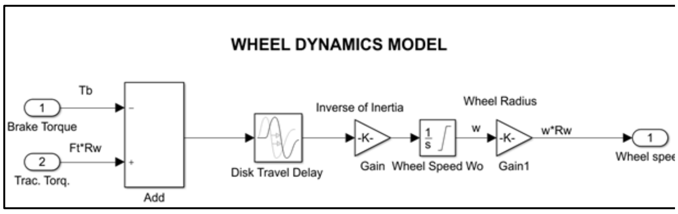


Fig.4: Simulation of Wheel Dynamics

C. *Wheel Slip Model:*

Slip is a relative motion between a tire and road surface. Velocity vector diagram and force vector diagram at wheel can be as follows:

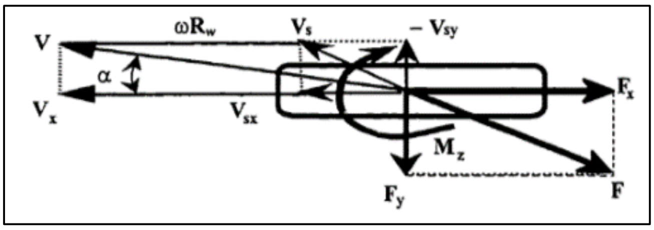


Fig.5: Wheel Slip Model

Where F_x=Total longitudinal force,
F_y =Total Lateral force,
M_z=Self aligning torque,
V=Vehicle speed in travel direction,
V_s=Slip Speed Vector,
α = Side Slip angle

The longitudinal Slip can be described as:

$$Slip = \frac{V\cos\alpha - \omega R_\omega}{V\cos\alpha}, \text{ taking } \alpha = 0$$

$$= \frac{V - \omega R_\omega}{V}$$

As per as equation, braking slip can be generated when wheel speed decelerating corresponding to the vehicle speed. Coefficient of friction can be expressed as a function of slip. Slip can be different with different road conditions.

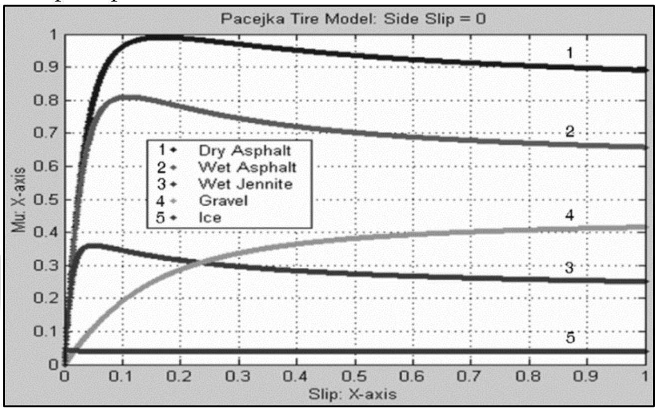


Fig.6: mu-Slip Curve for Different Road Conditions

D. *Final Simulation model:*

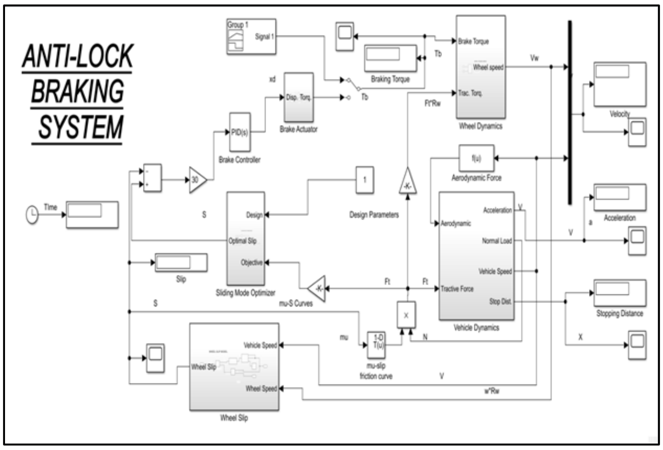


Fig.7: Complete Simulation Model

E. *Simulation without ABS Control System:*

For simulation purpose consider dry surface curve for a mu-slip relationship and applied braking torque is shown below.

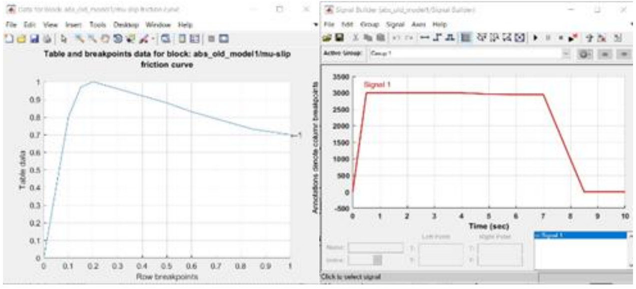


Fig.8: mu-slip curve for dry surface and applied braking force

For this condition response of the vehicle speed, wheel speed, braking slip and acceleration graph as per as shown below.

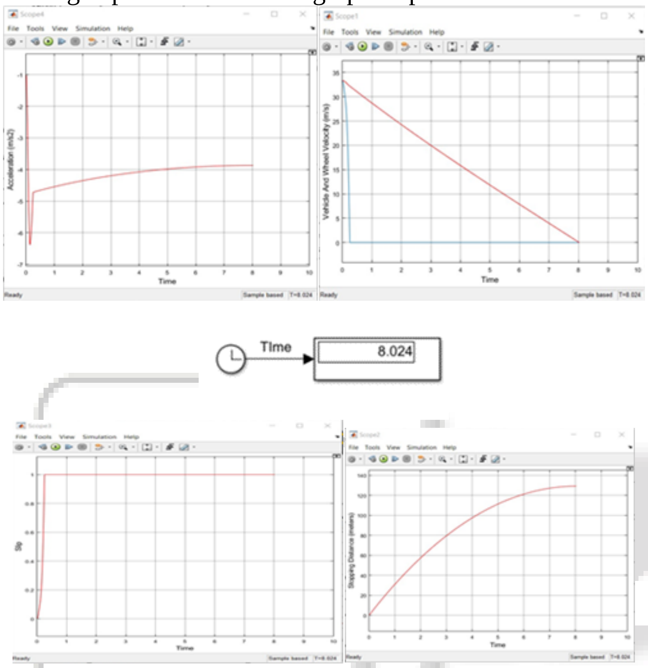
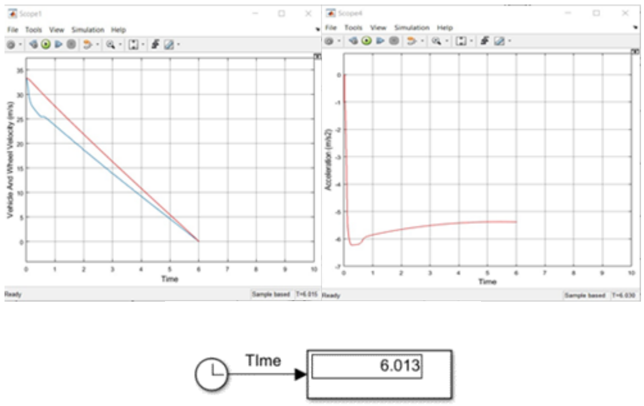


Fig.9: Results Graphs without ABS Control System

F. Simulation with ABS Control System:

A vehicle with a dry surface and brake torque input is the same as without ABS Control system.PID controller is used to maintaining brake torque and slip. And also sliding mode optimizer is activated with PID controller which continuously monitors coming slip from wheel slip block and try to maintain an optimal level. Optimal slip for the dry surface is 0.14 to 0.21



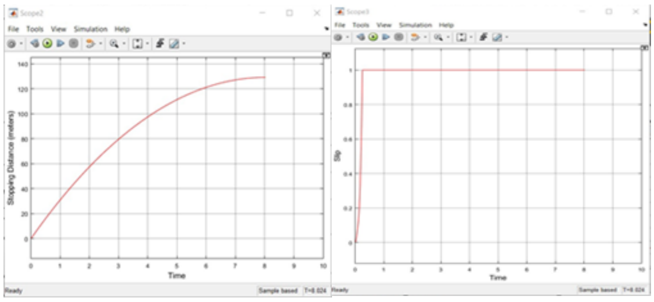


Fig.10: Results Graphs with ABS Control System

III. RESULTS:

Full Simulation model can be tested with maximum load, maximum vehicle speed. Then changed parameters in terms of vehicle speed and this table shows results with ABS control system and without ABS control system.

No.	Vehicle Speed (km/hr)	Vehicle Speed (m/s)	Stopping Distance(m) without ABS	Stopping Distance with ABS(m)	Time required to stop vehicle without ABS(s)	Time required to stop vehicle with ABS(s)
1	120	33.33	129.1	98.86	8.024	6.013
2	110	30.555	110.3	84.22	7.436	5.566
3	100	27.777	92.55	70.52	6.828	5.119
4	90	25	76.04	57.81	6.203	4.649
5	80	22.22	60.85	46.18	5.561	4.165
6	70	19.444	47.16	35.75	4.904	3.672
7	60	16.666	35.02	26.54	4.233	3.177
8	50	13.888	24.56	18.62	3.55	2.669
9	40	11.111	15.87	12.04	2.856	2.152
10	30	8.3395	9.007	6.862	2.154	1.63
11	20	5.5555	4.52	3.114	1.445	1.102
12	10	2.777	1.042	0.8289	0.7325	0.5658

Fig.11: Results from the Simulation Model

When vehicle is moving with 120km/hr, vehicle stopping distance will be 129.1m within 8.024 sec without ABS and with ABS control system it can be 98.86 m within 6.013 sec.

From the table data graph can be plotted for better understanding and performance analysis of ABS Control system.

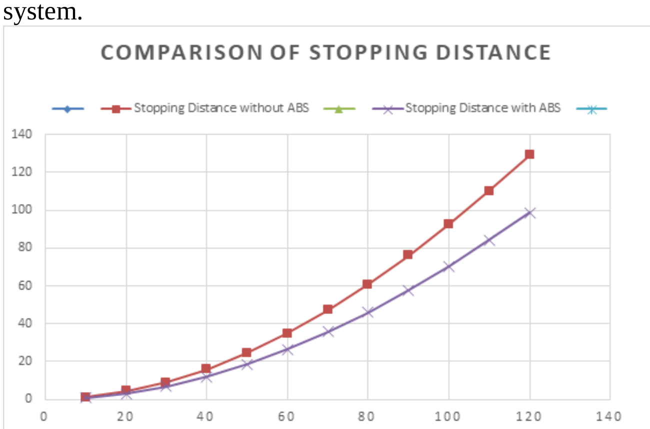


Fig.12: Stopping Distance Comparison with and without ABS Control System

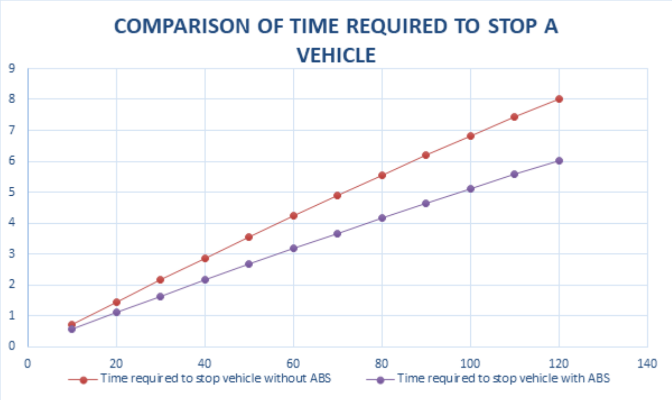


Fig.13: Time Required to Stop a Vehicle Comparison with and without ABS Control System

Graph results clearly show that ABS performance is increasing with an increase in vehicle speed. And ABS braking is more efficient than conventional braking in terms of stopping distance and stopping time.

IV. Conclusions

In this paper complete vehicle simulation without ABS Control system and with ABS control system is presented with MATLAB Simulink environment. Simulation results clearly shows that vehicle which contains ABS control system is more efficient in braking performance. It has more improved performance with good stability control which will help to avoid wheel lock during braking. Also conclude that braking performance is dependent on the road surface condition, tire-road friction coefficient and braking force distribution. ABS installation in vehicle provides good steering control and shorter stopping distance in minimum time period.

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