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Fuzzy based Adaptive Control of Antilock Braking System

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***Abstract*-ABS has been used to maintain the directional stability and maneuverability of road vehicles during emergency braking or when the road is slippery. ABS is an electronic feedback control system which prevent wheel lockup and maintain optimal wheel slip. But the system shows strong nonlinear characteristics which tends the vehicle to over steer and become unstable. This paper proposes introduction of slide mode optimizer which does an online check on the wheel slip to maintain stability. Slide mode optimizer is tuned by the fuzzy controller with a set of defined rules. Simulation results shows improvement of vehicle parameters like brake torque, deceleration, wheel slip, stopping distance.**

Keywords- Brake torque, stopping distance, fuzzy logic controller, sliding mode optimizer, SIMULINK

I. INTRODUCTION

The main function of ABS is to generate real time largest possible brake force along with vehicle maneuverability and to avoid excessive slip. ABS increases the vehicle stability by reducing the stopping distance and hence enhances the steering of the vehicle. ABS was first introduced in 1950, from then lot of control strategies have been implied, wherein the main objective is to improve the performance of the system. While designing the system, nonlinearity occurs due to the variation in parameters such as road condition, vehicle conditions, and uncertainty in sensor signals. PID controller is used because it characterizes the small amount of calculation, good real time date and easy to implement. There are few control strategies used such as variable structure control, adaptive control, fuzzy logic control. Fuzzy controller is used because it is very effective in handling uncertainties and complexities associated with the complex subsystems.

This Paper show the controllers designed for the ABS, where in input variables to the controller are obtained by wheel speed sensors and vehicle acceleration sensors. All the fuzzification process- defining membership function and framing rules is done under the Mamdani module. Objective is that wheel slip is maintained at desired level. Then the simulation results of normal ABS and ABS with controllers is compared.

The system consists of 5 subsystems namely- vehicle dynamics subsystem, wheel dynamics subsystem, wheel slip subsystem, slip mode optimizer subsystem and brake actuator subsystem. System is in a closed loop, such that brake actuation is the input which receives signals from output through slide mode optimizer, and the output is deceleration, stopping distance, and wheel slip.

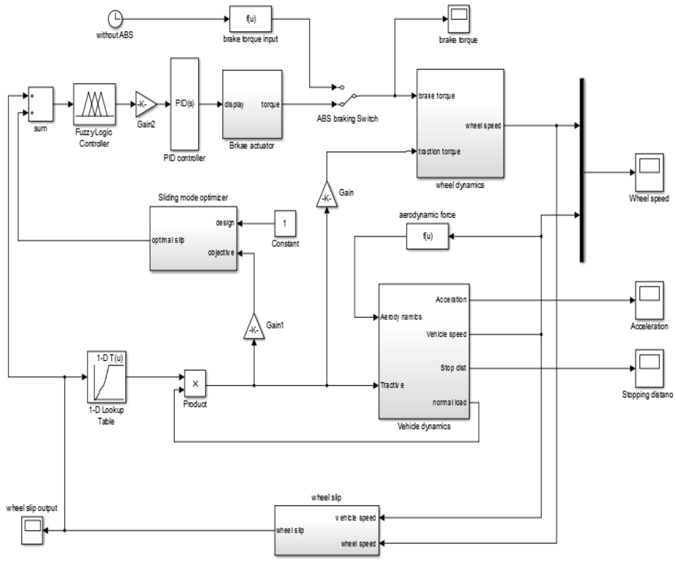

Fig1. ABS system

II. MODELING OF SYSTEMS

A. Brake actuator subsystem-This component controls the fluid flow to brake caliper and regulate braking pressure. The transfer function for the actuator system can be expressed by

$$F(u) = \frac{K_f}{M_p S^2 + B_f S + K_f}$$

Where M_p = Mass of prime mover
B_f = Fluid force friction coefficient
K_f=fluid stiffness coefficient

Brake torque is given by

$$\frac{T_b}{P_s - P_o} = K_t * e^{-t_o s}$$

Where T_b= Braking torque
P_s= caliper pressure
P_o=initial pressure for open check valve
K_t= specific torque constant
S = laplacian operator
t_o= dead time

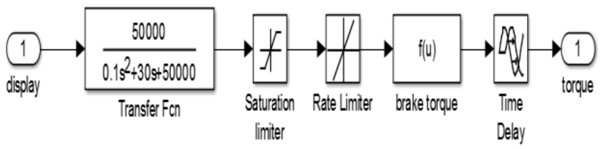

Fig2. Brake actuator subsystem

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B. Vehicle dynamics subsystem – This subsystem has a few important parameters to be considered during braking such as Aerodynamic force, tractive force, weight transfer load, and output such as stopping distance and deceleration are derived from the system.

Following expressions shows the relations of aerodynamic force, static weight load, and weight transfer load and normal load which are used in the block diagram.

1. Aerodynamic force = $\frac{1}{4}(\frac{\rho}{2} C_d A_f V^2)$
2. Static weight load = $M_t * g$
3. Weight transfer load = $\frac{M_c H_c}{2l} * V$
4. Normal load = (weight transfer load)-(static weight load)

Where ρ = Mass density of air

C_d = Wheel drag co-efficient

A_F= Wheel frontal area

M_t= Mass of tire and quarter vehicle mass

g= Acceleration due to gravity

M_c= Quarter vehicle mass

H_c= Centre of gravity height

l = Wheel base

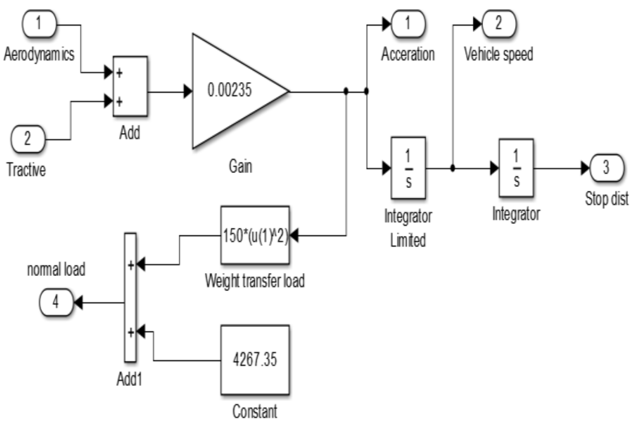

Fig3.Vehicle dynamics subsystem

C. Wheel dynamics subsystem – During braking, a stoppage torque is applied to the wheel, the wheel speed decreases and the vehicle speed also decreases. The system gets input from brake torque and traction torque, with a gain which is equal to wheel radius, wheel speed is taken as output from the subsystem.

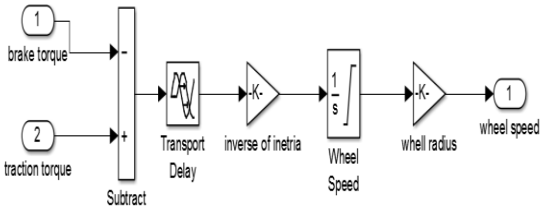

Fig4. Wheel dynamics subsystem

D. Wheel slip subsystem- Braking slip occurs as soon as the wheel decelerates to a rotational speed below which would normally correspond to a given vehicle velocity and vehicle velocity during deceleration, hence the wheel speed and vehicle speed are the input for the system. This is the region in which braking is generated. The output from this subsystem gives percentage wheel slip.

Wheel slip is given by the following expression

Wheel slip = (V - $\omega * R_\omega$) / V

Where V – vehicle speed

ω – Wheel speed

R_ω- Wheel radius

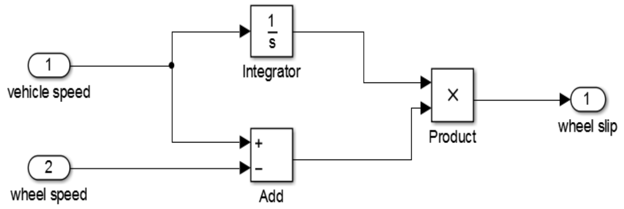

Fig5. Wheel slip subsystem

E. Sliding mode optimizer- The system combines a sliding mode based optimizer, PID controller and fuzzy controller. The sliding mode optimizer performs an on-line search for optimal wheel slip that corresponds to vehicle's maximum deceleration.

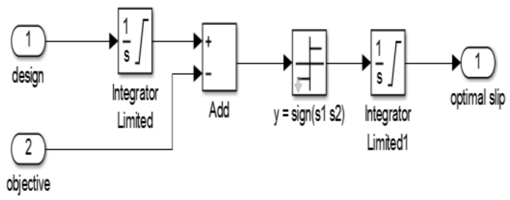

Fig6. Sliding mode optimizer subsystem

III. FUZZY CONTROLLER

Fuzzy controller is an intelligent, knowledge based control methodology which performs well in nonlinear, complex and without mathematically describable systems. Hence fuzzy is most suited for ABS. Without fuzzy braking pressure reaches a very high level and wheel locks within short distance, but with fuzzy controller steer ability is retained along with increasing the vehicle stability.

In this paper the fuzzification process is carried on based on Mamdani type fuzzy inference system. There are three inputs which is obtained from the model namely vehicle

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velocity, wheel velocity and percentage slip. The output from the controller is the brake pressure actuation.

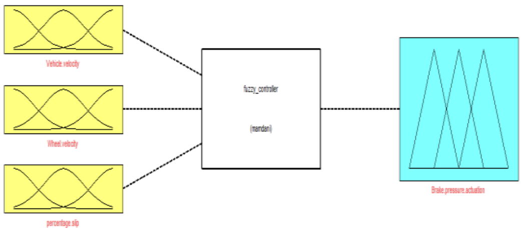

Fig7. Fuzzy controller inputs and output

Each input and output is given 3 membership functions namely Low, Medium and high with range of values for each functions as shown. Triangular membership function is used for all the inputs and outputs.80 rules have been defined relating input and output shown in fig.9 and the graph is obtained in the surface viewer as shown in fig10.

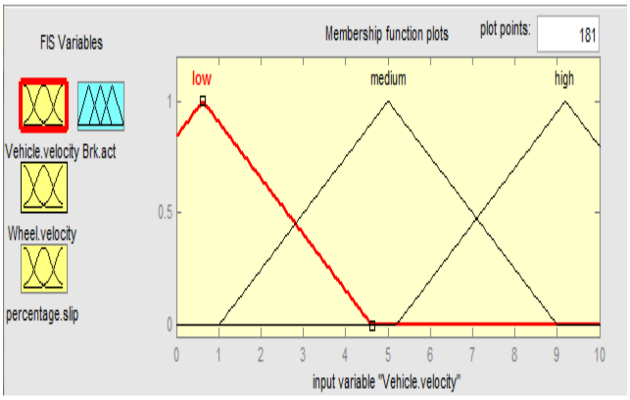

Fig8. Defined membership functions

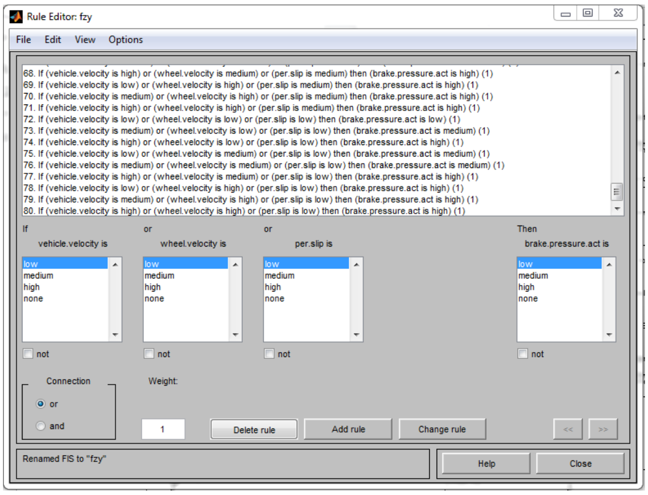

Fig9. Rules relating input and output

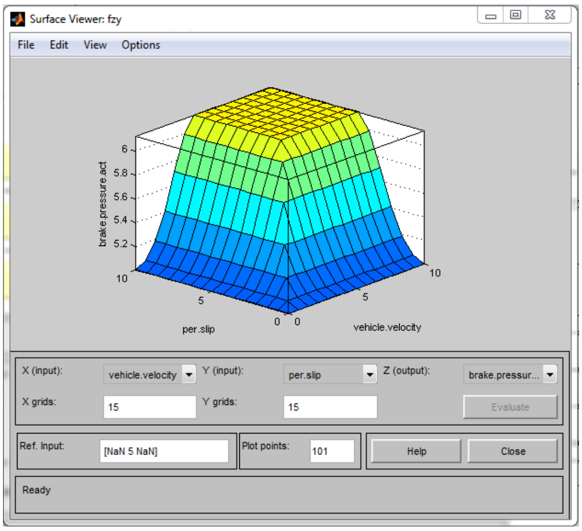

Fig10. Surface viewer of defined rules

IV. SIMULATION PARAMETERS

Parameter	Value
Mass of tire	40 kg
Quarter vehicle mass	375 kg
Centre of gravity height	0.5 m
Wheel base	2.5 m
Wheel radius	0.326 m
Co-efficient of friction	0.45
Brake caliper pressure	6.895 kpa
Check valve pressure	6.5 kpa
Specific torque constant	1.7

Table1- parameters used in simulation

V. SIMULATION RESULTS

The figures shows the comparison of the brake torque applied to a vehicle model. The comparison is made between normal braking ABS braking and ABS braking with fuzzy controller. Based on the results, the fuzzy controller shows the improved vehicle stability.

1. Brake torque vs time

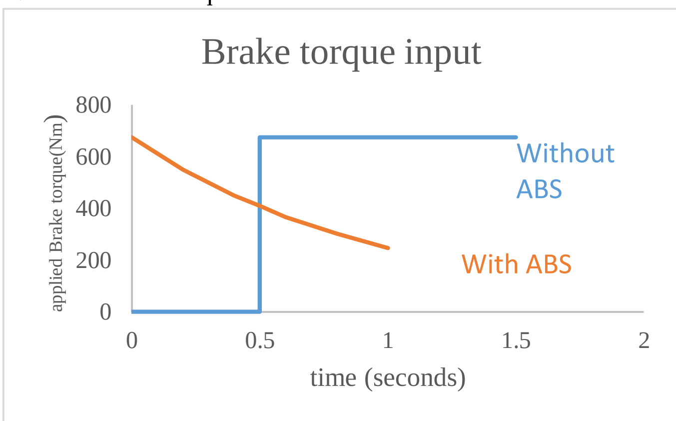

Fig10. Comparison of braking torque

Graph shows that the brake torque of 650 Nm applied at about 0.5 seconds, non-ABS system has impact braking at 0.5 seconds and the vehicle stops, whereas in system with ABS and controllers has linear braking(with simultaneous switching on and off) and vehicle comes to stop gradually.

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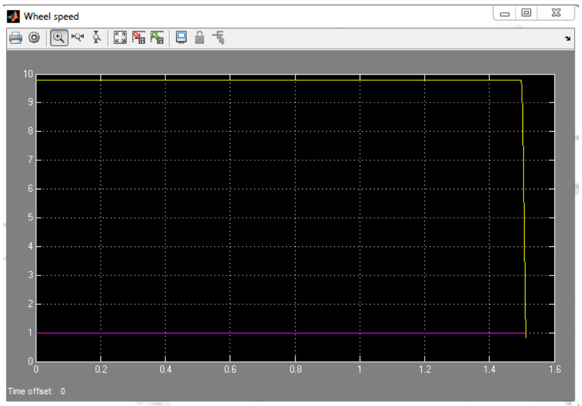
2. Wheel speed vs time



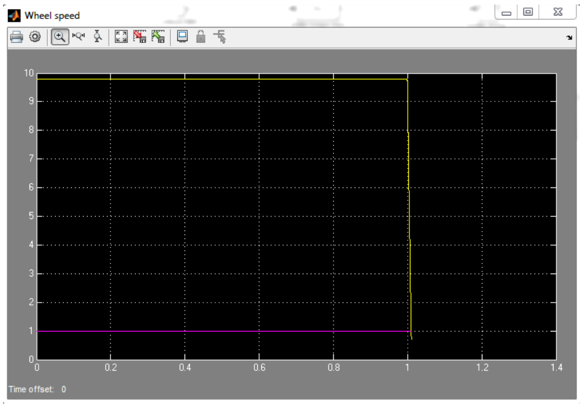
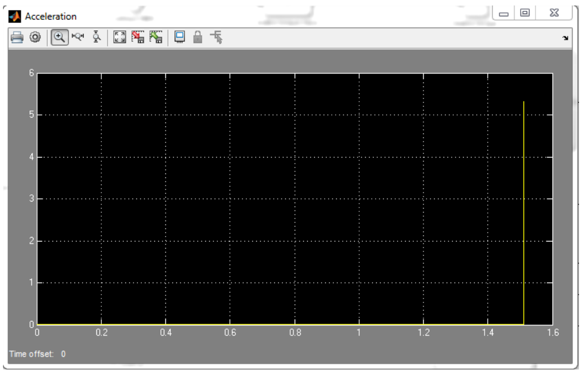


Fig11. Comparison of wheel speed
(a) With ABS
(b) With intelligent ABS

It is clear from the graph that with the normal ABS operation the speed of the vehicle is reduced and comes to rest at 1.5 seconds, wherein the intelligent ABS operation achieves the same at 1 second.

3. Acceleration vs time



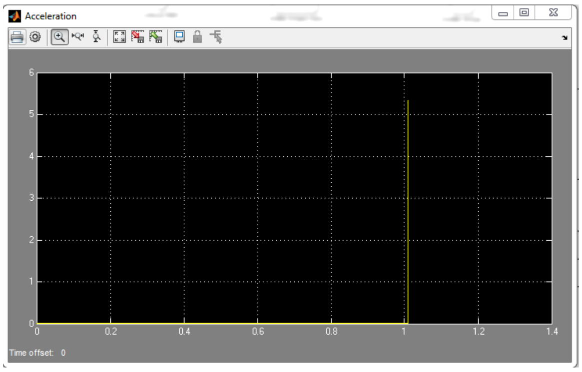
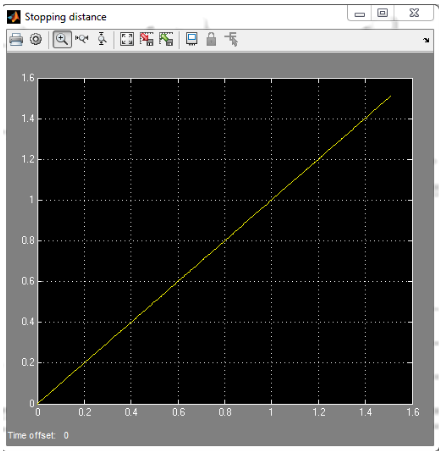


Fig12. Comparison of acceleration
(a) With ABS
(b) With intelligent ABS

Graph shows that the deceleration of the vehicle starts at 1.5 seconds in normal ABS operation, and it starts at 1 second in intelligent ABS system.

4. Stopping distance vs time



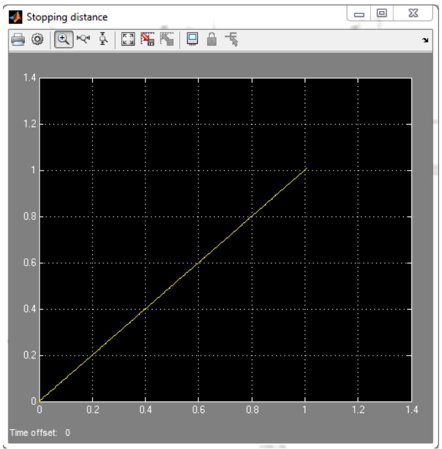


Fig13. Comparison of stopping distance
(a) With ABS
(b) With intelligent ABS

With Normal functioning of ABS the vehicle stops at 1.5m taking 1.5 seconds to stop, but in intelligent ABS system the vehicle stops at 1 second itself covering a distance of 1 m. Hence the stopping distance of 0.5m is reduced and at the same place time taken is also reduced. This shows the improvement of performance in vehicle characteristics.

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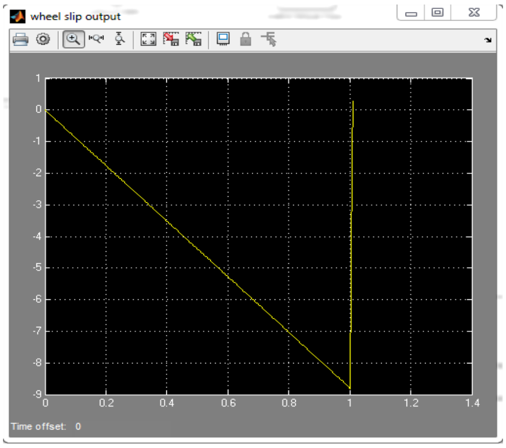
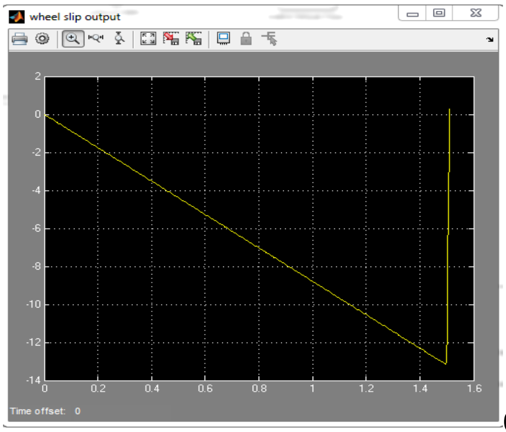
5. Wheel slip vs time



(a)



(b)

Fig14. Comparison of wheel slip
(c) With ABS
(d) With intelligent ABS

This is an important output driven out from the system. The graph output from the scope of MATLAB Simulink system shows that the wheel slip in normal ABS happens at 1 second and with intelligent ABS appears at 1.5 seconds. Elongation of slip time improves the vehicle stability, since slip is the main factor which in turn causes the wheel lock.

CONCLUSION

Basically an ABS system for a vehicle model is modeled using Matlab SIMULINK. Simulation is run and various outputs are obtained. Then Fuzzy controller is modeled by defining inputs-outputs, rules, and the obtained controller is introduced to the system and simulated again. The outputs after adding the controller and with normal ABS operation are obtained and compared. System output from simulations shows improvement in vehicle characteristics such as wheel speed, deceleration, brake torque, and also gradual improvement in system stability factors such as wheel slip and stopping distance.

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