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Design and Analysis of Antilock Braking System with Fuzzy Controller for Motorcycle

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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, study of Motorcycle Antilock Braking System (ABS) is given. In literature survey study of various controller based ABS systems are studied which are commercially used in passenger vehicles, trucks, Buses, etc. The aim of this work is to design Fuzzy logic Based ABS controller for motorcycle in order to obtain desired braking performance to prevent wheel locking considering motorcycle wheel dimensions. The stopping distance, braking torque are calculated analytically and Performance is verified in MATLAB/Simulink Environment.

***Key Words*: Motorcycle Antilock Braking System (ABS), Fuzzy Logic, Stopping Distance, MATLAB/Simulink.**

1. INTRODUCTION

Anti-lock braking system (ABS) is an important development for vehicle safety in recent years. When a vehicle is under emergency braking, the ABS can prevent the wheels from skidding and the vehicle from spinning. Thus, the vehicle can be kept under desired control and in some circumstances, it can shorten the vehicle's braking distance. With the hydraulic pressure regulator in the system, it can reduce the pressure of the braking oil and retain the appropriate rolling of the tire. In most passenger cars, ABS has become a standard safety equipment and is a mature product. Compared to passenger cars, maneuvering a motorcycle is more unstable and dangerous during braking. It can easily slide and sideslip and, thus, result in overturn and accident. However, due to the cost consideration and space limitation, motorcycles equipped with the ABS system are less popular. Therefore, many motorcycle companies and researchers have begun to develop a better ABS system for motorcycles. Braking performance of vehicle is one of the most important characteristics which affect vehicle safety. Stopping distance is an important parameter widely used for evaluating the overall braking performance of a road vehicle. Main parameters affecting the brake stopping distance are listed as:

1. Vehicle weight

2. Vehicle speed

3. Coefficient of road adhesion

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 made compulsory 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.

Out of different control logic Fuzzy logic is the best way to get a solution over this complex model. Most of the control systems in car involve complex parameters and optimization of such things is dealt by engineering expertise with less use of mathematical model. Fuzzy logic provides a great platform to reach towards the solutions by minimizing the calculations. Fuzzy logic uses the linguistic variables which eliminates the tedious calculations.

1.1 Antilock Braking System (ABS)

ABS systems use a combination of electronic and hydraulic

Systems to modulate the brakes individually to prevent them from locking. The directional stability of the vehicle, to sustain stable vehicle orientation even under conditions such as sudden braking and slippery road surfaces. 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. As long as the wheels are rotating slowly, device permits normal application of the brakes. But if the brakes are applied so hard that the wheel tends to stop turning and a skid starts to develop then the device comes to operation.

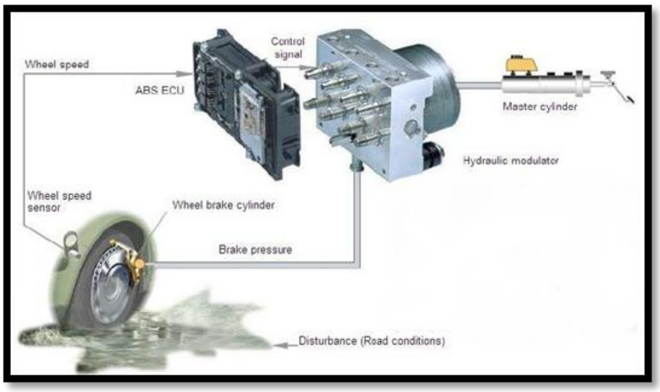

Fig.1 Components of ABS

1.2 Components of ABS

1. Wheel-Speed Sensors : They monitor the rotational speed of the wheels and the vehicle.
2. Electronic Control Unit (ECU) : ECU calculate slip ratio and generate optimum braking torque in order to prevent wheel locking.
3. 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.
4. Solenoid Valve: 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.
5. Disc Brakes: 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.

2. OBJECTIVE

To reduce the stopping distance of motorcycle while Braking using Fuzzy based Antilock Braking System so as to Avoid the skidding and improving the steerability of motorcycle while emergency or hard braking.

3. ANALYTICAL DESIGN USING KINETIC ENERGY APPROACH

- Slip Ratio(λ):

$$\lambda = \frac{V - R\omega}{V} \tag{1}$$

As, 'λ' varies from 0 to 1.

- μ Calculation Formulae:

$$\mu(\lambda) = (C_1 * (1 - e^{-(C_2\lambda)}) - C_3\lambda) \tag{2}$$

Where,
C_1, C_2, C_3 are the constants and Values of constants for different road conditions are as follows:

Surface Condition	C_1	C_2	C_3
Dry asphalt	1.2801	23.99	0.52
Wet asphalt	0.857	33.822	0.347
Concrete	1.1973	25.168	0.5373
Ice	0.05	306.39	0

Table 1: Values of C_1, C_2 and C3 for different road

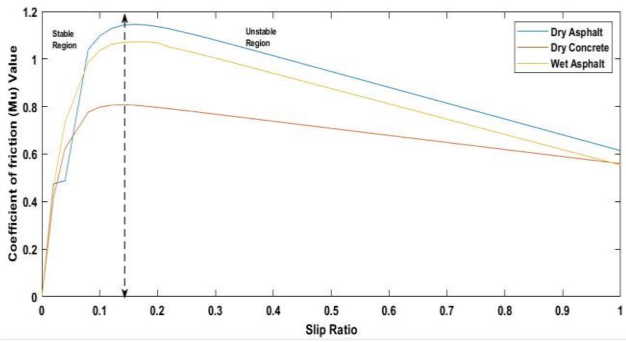

Fig.2 Mu-Slip Curve for various road surfaces

- K.E. Formulae :

$$K.E. = \frac{1}{2} * m * V^2 \tag{3}$$

Where,

m = Mass of (Vehicle + Rider) = 250 Kg

- Tire Friction Force(F_t) :

$$(F_t) = \mu * m * g \tag{4}$$

- Stopping Distance(S) :

$$F_t * S = K.E \tag{5}$$

Hence,

$$S = \frac{K.E.}{Tire-Friction\ Force(F_t)} \tag{6}$$

3.1 Tyre-Friction Force & Stopping Distance for dry road surface at different velocities

μ Values	Tyre-Friction Force	Stopping distance for different velocities (Velocities in KMPH)	
		30	**60**
0.4	784.8	29.49	62.6289
0.5	981	23.5964	50.1032
0.7	1373.4	16.8546	35.788

Table 2: Stopping Distance & Tire-Friction Force

3.2 Brake Force & Brake Torque Calculations

A_1=Area of Master Cylinder Piston

$$= \frac{\Pi}{4} * d_1^2$$

A_1= 201.0619mm^2

A_2=Area of Calliper Piston

$$= \frac{\Pi}{4} * d_2^2$$

A_2= 804.2477mm^2

Now,

By Pascal's Law,

$$P_{master\_cyl.\_piston} = P_{calliper\_piston}$$

$$P = \frac{F}{A} = \frac{F_1}{A_1} = \frac{F_2}{A_2} \quad (7)$$

Hence,

$$F_2 = F_1 * (A_2/A_1) \quad (8)$$

As Caliper pressure acts on both the side of disc,

The Braking torque (T_b) is given by,

$$T_b = 2*(\mu')*F_2*r_{disc} \quad (9)$$

F1(N)	F2(N)	Braking Torque(Tb)	
		μ' = 0.5	**μ' = 0.6**
45	360	43.2	51.84
50	400	48	57.6

Table 3: Brake Torque Calculations

Where,

μ' is the Coefficient of friction between brake caliper and brake disc.

4. MATHEMATICAL MODELLING

To develop the mathematical model of Antilock Braking System for Bike with and without Controller in the Matlab Simulink **Newton's Second Law** of Motion is used.

Newton's Second Law of Motion: *It states that, the rate of Change of Linear Momentum (i.e. **P = M*V**) of any Body is Proportional to Force Applied and it takes place in the direction of Force.*

Formulas used for developing mathematical model are as follows,

Longitudinal Force is given by,

$$F = m*a \quad (1)$$

Frictional force is given by,

$$F = -\mu * F_N \quad (2)$$

Equations of motion are given by,

$$m*a = -\mu * F_N \quad (3)$$

$$J\omega * \alpha = \mu * F_N * R - Tb \quad (4)$$

Hence, state of model can be determined by following equations,

$$a = \frac{-\mu * FN}{m} \quad (5)$$

$$\alpha = \frac{\mu * FN * R - Tb}{J\omega} \quad (6)$$

Slip ratio is defined as,

$$\lambda = \frac{V - R*\omega}{V} \quad (7)$$

4.1 2-Wheeler ABS Mathematical Model without Controller

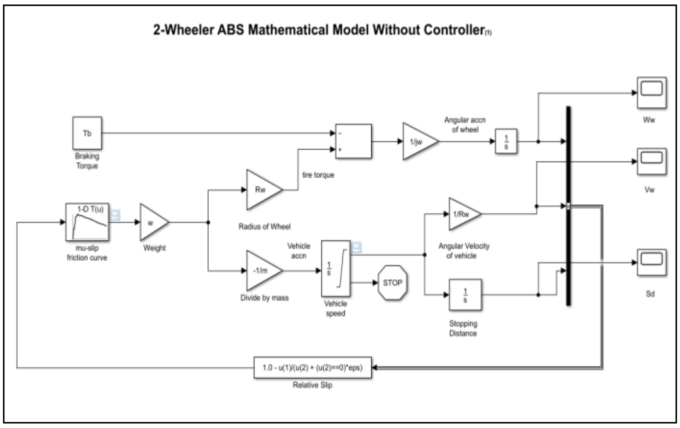

Fig.3 Wheeler ABS Mathematical Model without Controller

4.2 Fuzzy Logic Controller Design

A fuzzy logic controller consists of three main operations i.e. Fuzzification, Inference Engine and Defuzzification.

The linguistic variables are then used in the antecedents (IF-Part)of a set of fuzzy IF-THEN rules within an inference engine to result in a new set of fuzzy linguistic variables or consequent (THEN-Part) in the inference engine .for this Mamdani rule base system is used.Modelling a Mamdani rule base requires three steps:

a. The input domain and output range has to been determined for appropriate fuzzy sets.
b. Determine a set of rules between the fuzzy inputs and the fuzzy outputs that model system behavior.
c. A framework is created to map crisp inputs to crisp outputs.

4.2.1 Fuzzy Logic Block Diagram

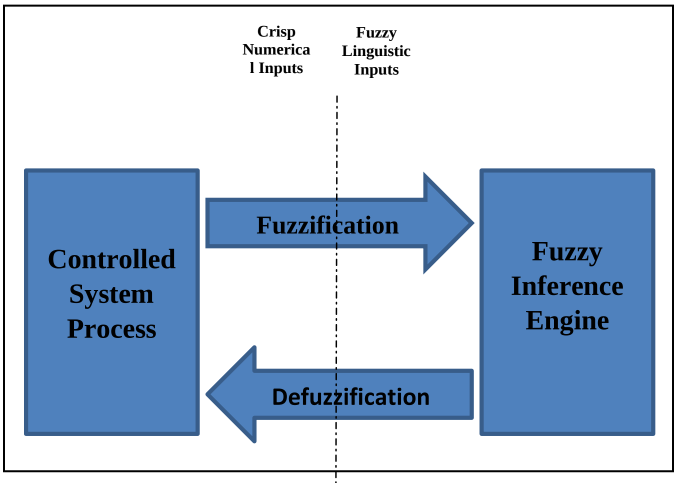

Fig.4 Fuzzy Logic Block Diagram

4.2.2 Fuzzy Logic Controller Design for ABS

a. The controller selected is Mamdani Fuzzy Logic Controller (FLC) having two inputs and single output. The two inputs are slip error (E) and rate of change of slip error (CE) and single output is Brake Torque (Tb).
b. Both are having five membership functions each.
c. The membership function of slip error and rate of change of slip error requires a high sensitivity, so triangular function is selected.
d. The membership function of output braking torque is also high hence Triangular function is selected.

The Language value of input and output parameter are **N** is Negative, **NS** is Negative Small, **ZE** is Zero, **PS** is Positive Small, **P** is Positive.

- The rules are developed in the form of,

IF (E) IS.....AND (CE) IS....THEN (Tb) IS....

The Control fuzzy Rules are developed based on following table,

(CE)→ (E)↓	N	NS	ZE	PS	P
N	ZE	ZE	PVS	PVS	PS
NS	ZE	PVS	PVS	ZE	PS
ZE	PS	PVS	ZE	PS	PS
PS	PS	ZE	PS	PVS	P
P	ZE	ZE	PVS	PS	PVS

Table 4 Fuzzy Rule-Base Table

4.2.3 Description of some Fuzzy Rule Base Cases

Consider when slip error **(E)** is **N** and rate of change of slip error **(CE)** is **N** then torque **(Tb)** required be **ZE**.This implies that when slip error and rate of change of slip error are not in control then there should be no torque required to apply in order to achieve required stopping distance.

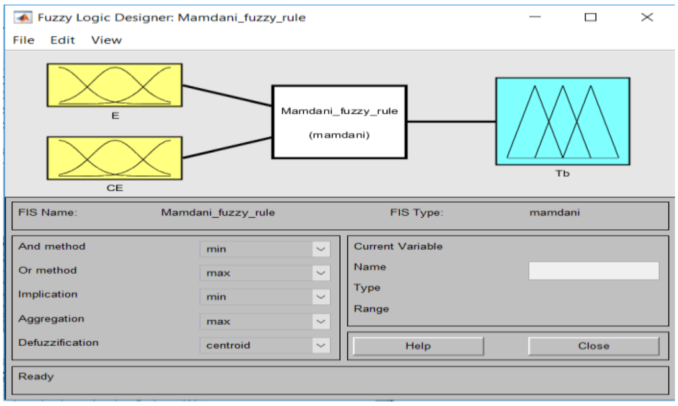

Fig 5 Fuzzy Controller Input and Output

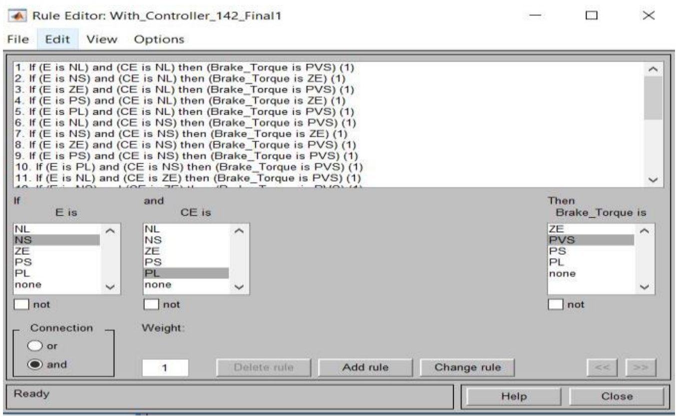

Fig 6 Rule Relating input and Output

4.3 2-Wheeler ABS Mathematical Model with Controller

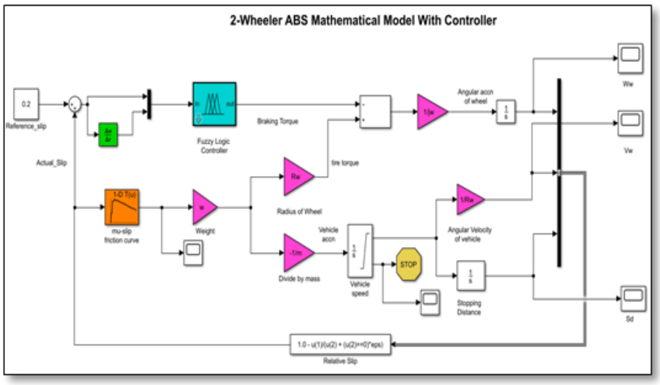

Fig 7 2-Wheeler ABS Mathematical Model with Controller

4.4 Simulation Parameter

Parameter	Name	Value
Mass (vehicle + Rider)	m	250 KG
Inertia	Jw	2.2275 Kgm^2
Braking Torque	Tb	60 Nm
Weight	w	2452.5 N
Wheel Speed	Ww	31.02 and 62.05 Rad/sec
Vehicle Speed	Vw	8.33 and 16.66 m/s
Gravitational Force	g	9.81 m/s^2
Co-efficient of friction	μ	0 to 1
Dia. of Master Cylinder Piston	d_1	16 mm
Dia. of Caliper Piston	d_2	32 mm
Force of Master Cylinder Piston	F_1	Calculated (N)
Force of Caliper Piston	F_2	Calculated (N)
Area of Master Cylinder Piston	A_1	Calculated (mm$_2$)
Ares of Caliper Piston	A_2	Calculated (mm$_2$)
Radius of wheel	R	0.2686 mm
Radius of disc	r	0.12 mm
Slip Ratio	λ	0 to 1

Table 5 Simultion Parameters

5. RESULTS

A. For 30 KMPH Speed

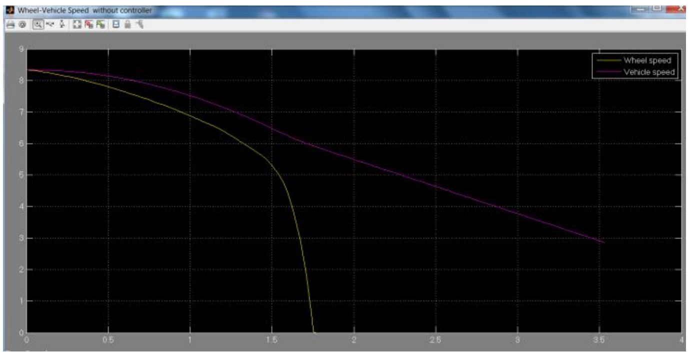

Fig 8 Vehicle speed vs Wheel Speed without controller

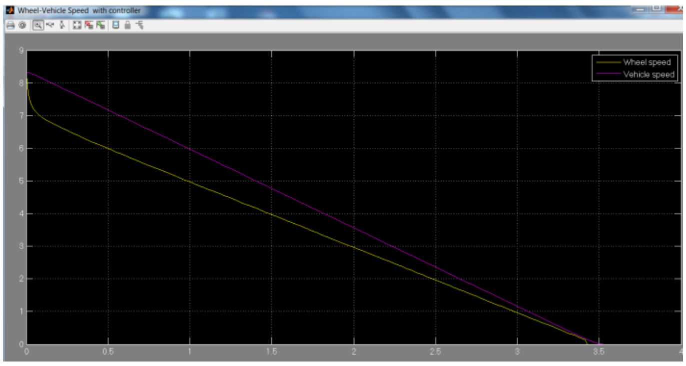

Fig 9 Vehicle speed vs Wheel Speed with controller

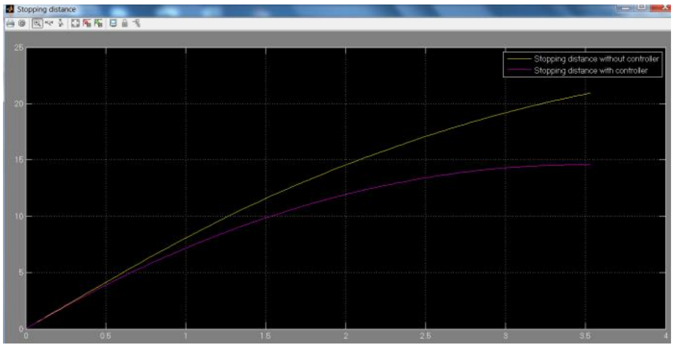

Fig 10 Stopping Distance with and without controller

B. For 60 KMPH Speed

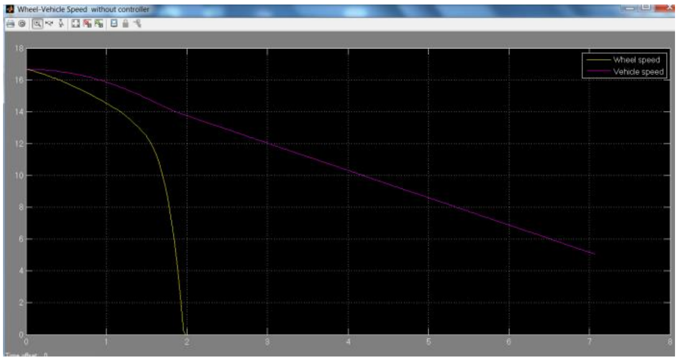

Fig 11 Vehicle speed vs Wheel Speed without controller

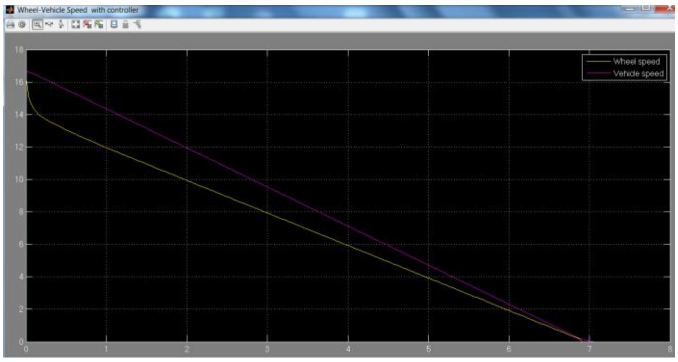

Fig 12 Vehicle speed vs Wheel Speed with controller

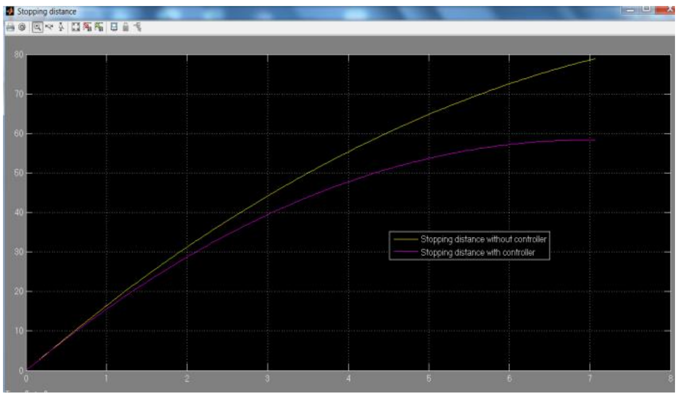

Fig 13 Stopping Distance with and without controller

C. Result Table

Speed		Stopping Distance (m)	
KMPH	m/sec	Without controller	With controller
30	8.3333	22.16	14.82
60	16.6666	76.58	58.12

Table 6 Result Table

6. CONCLUSIONS

In this work Antilock Braking system for vehicle is modeled using Matlab Simulink. Main focus is to reduce the stopping distance of vehicle while braking using fuzzy logic controller. For comparison point of view two approaches are used to calculate stopping distance of vehicle. Model is run at 30 KMPH and 60 KMPH as per testing standard and results are obtained.as fuzzy controller is modeled by defining input-outputs, if-then fuzzy rules.Based on fuzzy control, ABS can effectively prevent the wheels from locking,braking more efficiently by reaching more optimum slip ratio at 0.2 .Hence, fuzzy controller reduces the stopping distance than the without controller model and avoid the locking and slipping of wheel as without controller model.

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