Influence of the Working Performance of ABS Brake System with Applying Different Control Algorithm

Vu Hai Quan[1], Nguyen Anh Ngoc[1*], Nguyen Trong Duc[2]

[1]*School of Mechanics and Automotive Engineering – Hanoi University of Industry, Vietnam*

[2]*Moscow Automobile and Road Construction State Technical University (MADI), Moscow 125319, Russia Federation*

Abstract: This study focuses on enhancing brake system handling techniques for improved traffic safety. The research analyzes the performance of the ABS braking system using two control algorithms: PID and Fuzzy Logic. The simulation reveals that the system employing the PID control algorithm, determined through the Ziegler-Nichols method, outperforms others, achieving shorter braking distances and times in Matlab – Simulink software. The simulation results have demonstrated that the performance of the braking system using the PID controller yields better outcomes compared to other systems. The system is highly suitable for tight parking spaces, congested traffic conditions, emergency situations, and limited areas. The simulated results show reliable and stable performance when employing the ABS system with PID control, making it more likely to be accepted by consumers.

Keywords*: Automatic braking system; AEB; Fuzzy Logic, ABS, PID.*

1. Introduction

To avoid accidents or minimize casualties resulting from collisions between vehicles, the braking system plays a crucial role. However, the braking system needs to be set up to brake within an appropriate timeframe for the given circumstances [1, 2]. If the system is not activated at the right time, it may be challenging to prevent or minimize collisions between vehicles [3].

The World Health Organization [4] reports that the global annual death toll from road traffic accidents has reached 1.35 million people. This means that one person is killed every 25 seconds. Seventy-four percent of road traffic deaths occur in middle-income countries, accounting for only 53% of registered vehicles worldwide. In low-income countries, the situation is even worse. Only 1% of the world's cars cause 16% of road traffic deaths globally [5]. This indicates that these countries bear a disproportionately high burden of road traffic deaths compared to their level of motorization [6]. These accidents occur everywhere and anytime, causing severe damage, serious injuries, and fatalities, with a significant portion attributed to driver distraction and failure to brake [12]. In a study by Jessica B. Cicchino and Volker Sandner, the use of Autonomous Emergency Braking (AEB) with pedestrian detection was found to significantly reduce the risk of pedestrian collisions by 25%-27% and the risk of pedestrian injury by 29%-30% [5, 7]. Numerous studies focus on the design and development of intelligent emergency braking systems [8, 9]. On research “Fabrication of automatic braking system using ultrasonic sensor”, “Design and Analysis of Intelligent Braking System” and “Design an intelligent braking system using ultrasonic sensors and IR sensors”, utilized ultrasonic systems with sensors on each wheel to regulate brake pressure and maintain a safe distance [10, 11], [12] . This system is cost-effective and has the potential to reduce accidents significantly [13]. In the study "Adaptive Neuro Fuzzy Inference System Based controller for Electric Vehicle’s hybrid ABS braking," an ANFIS controller for Electric Vehicle Anti- lock Braking System (ABS) was proposed, showing superior performance in various aspects compared to other controllers [14]. Additionally, a new PID control scheme was introduced to stabilize the wheel and improve braking performance [15]. Fuzzy logic has a variable input and output variables. Input variables used in this research is the distance between car and obstacle; the speed of car prototype and the output variable is the brake angle [16].

The research objective is to analyze the braking system's performance through simulation using Matlab/Simulink in four cases: a braking system without ABS, a braking system with ABS, a braking system using Fuzzy Logic control algorithm, and a braking system using PID control algorithm. The study identifies the limitations of a braking system without ABS, emphasizing the importance of controlling brake torque accurately to prevent wheel lock-up and sliding during braking [17]. The control objective is to maintain wheel slip as close to the optimal target value as possible to minimize stopping distance while ensuring stability within an acceptable range. Fuzzy logic rules are developed for obstacle detection and braking to control the system's operation and ensure safe driving. The ABS braking system with Fuzzy Logic control automates situation assessment and determines the precise brake pressure to avoid collisions, significantly reducing property and financial damage caused by accidents [18]. The PID controller in the ABS braking system was implemented and analyzed using Matlab/Simulink. The controller parameters were optimized using a genetic algorithm to control wheel slip and stopping distance effectively.

2. Building a mathematical model

The mathematical model is the initial basis for developing a control algorithm for ABS. In this article, a mathematical model is built which is a quarter car model. In it, various equations and mathematical expressions are used to model various components, including: vehicle dynamics, wheel slippage, tires, brake actuators

2.1 Vehicle dynamics

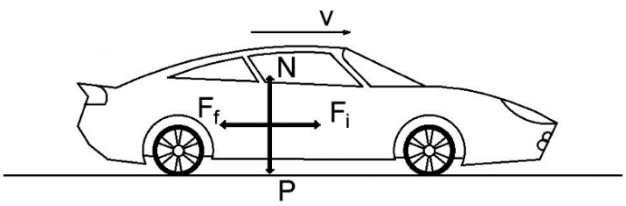

Figure 1. Vehicle dynamics model

Assuming that, The vehicle performs the braking process under conditions of uniform motion, then we can write the balance equation as follows [19]:

- for horizontal direction:

$$F_f = F_i \tag{1}$$

In there: F_f [N] - is the rolling resistance between the wheel and the road surface

F_i [N] - is the inertial force of the vehicle's motion

- for vertical direction:

$$N = P \tag{2}$$

In there: N [N] - normal force (reaction of the line)

P [N] - vehicle weight

Rolling resistance can be determined through the following formula:

$$F_f = \mu . N \tag{3}$$

Among them: μ [-] rolling resistance coefficient between wheel and road.

The weight of x e is determined:

$$P = m_v . g \tag{4}$$

Substituting (2) and (4) into (3), we get the expression to determine rolling resistance as:

$$F_f = \mu . m_v . g \tag{5}$$

In there: m_v [kg] - is the total mass of the vehicle

g [m/s ^{2}] - is the gravitational acceleration

The inertial force of motion is the product between the mass of the vehicle m_v [kg] and the acceleration of the vehicle a_v [m/s ^{2}]:

$$F_i = m_v.a_v = m_v.\frac{dv_v}{dt} \tag{6}$$

Among them: v_v [m/s] is the speed of the vehicle.
From equations (1), (5) and (6) we can derive the expression to determine the vehicle acceleration:

$$\frac{dv_v}{dt} = \frac{1}{m_v}.(\mu.m_v.g) \tag{7}$$

The vehicle's speed is determined by integrating equation (7).

2.2 Wheel model

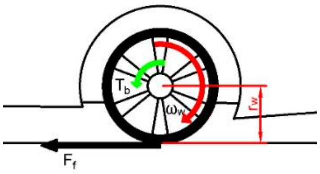

Figure 2. Tire dynamics model

During the braking process, through the brake drive system, the driver applies the braking torque T_b [Nm] to the wheels. The rolling resistance force F_f [N] between the wheel and the road creates a moment opposite to the wheel radius r_w [m].

For simplicity, we will assume that the wheel is absolutely rigid and that the reaction force of the road surface is transmitted through the wheel axle, thus creating no additional torque [5].
Therefore, the wheel's dynamic equation can be written as follows:

$$T_b - F_f.r_w - I.\frac{d\omega_w}{dt} = 0 \tag{8}$$

In there: I [kg.m ^{2}] - is the moment of inertia of the wheel
ω_w [rad/s] - is the angular speed of the wheel
From equation (8) we can derive the expression to determine the wheel acceleration:

$$\frac{d\omega_w}{dt} = \frac{1}{I}.(T_b - F_f.r_w) \tag{9}$$

The speed of the wheel is determined by integrating equation (9).

2.3 Wheel slippage

The ABS braking system must control wheel slippage λ [-] around an optimal target. Wheel slippage is calculated as follows:

$$\lambda = 1 - \frac{\omega_w}{\omega_v} \tag{10}$$

In which: ω_v [rad/s] is the relative angular speed of the vehicle, calculated by the formula:

$$\omega_v = \frac{v_v}{r_w} \tag{11}$$

In which: v_v [m/s] is the speed of the vehicle.

2.4 Braking torque

Automotive brake model refers to the relationship model between braking torque and air hydraulic pressure of the braking system. When the car is braking, it must first overcome the spring return force in the brake and brake cylinder. Letting this force be P_m, the corresponding braking moment can be expressed by the following formula:

$$\begin{cases} T_p = 0 & P < P_m \\ T_p = K_f(P - P_m) & P > P_m \end{cases} \tag{12}$$

In the formula:

T_p is the braking torque (Nm);

K_f is the braking coefficient (Nm/kPa);
P is the brake air-hydraulic pressure (kPa);
P_m is the amount of air needed to overcome the spring's elastic force. Hydraulic pressure (kPa).

Due to the clearance and friction of various mechanical parts in the brake, brake hysteresis and other strongly non-linear dynamic characteristics are caused, which causes great difficulties for brake modeling. To facilitate the study of control algorithms, this paper assumes the brake to be an ideal component in the simulation process, ignoring the effect of hysteresis. Therefore, the braking equation is:

$$T_p = K_f . P \quad (13)$$

3. Build a simulation model of intelligent brake system

3.1 Controller bang-bang

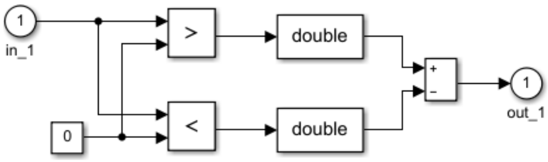

Figure 3: Bang-bang controller block

The controller here is quite simple. It is a controller that operates according to feedback signals from wheel slippage to simulate an ABS controller. To control the rate of change of brake pressure, we take the input parameter by subtracting the actual slip from the desired slip, and feed this signal into the bang-bang controller. Depending on the indication of the error, the signal that will be output is:

- 1 if 0.2 - λ_{tt}> 0
- -1 if 0.2 – λ_{tt}< 0

This on/off ratio passes through a first-order hysteresis representing the hysteresis associated with the brake system's hydraulic lines. Then, integrate to find the actual brake pressure. The resulting signal, multiplied by the piston area and radius with respect to the wheel (K_f) is the braking torque applied to the wheel car.
Friction force on the wheel with the wheel radius (r_w) to calculate torque family speed belong to face road above the wheel. Subtract the braking torque from the acceleration torque to create the net torque on the wheel. Divide the net torque by the moment of inertia I, creating the wheel's acceleration, then integrate to calculate the wheel's angular velocity.

$$w_w = \int \frac{T_b - M_p}{I} \quad (17)$$

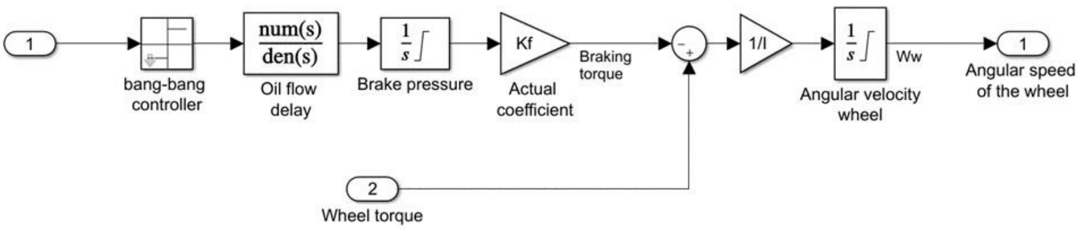

Figure 4: Wheel angular speed simulation block

3 .2 The brake system uses Fuzzy logic controller

3.2.1 Block diagram

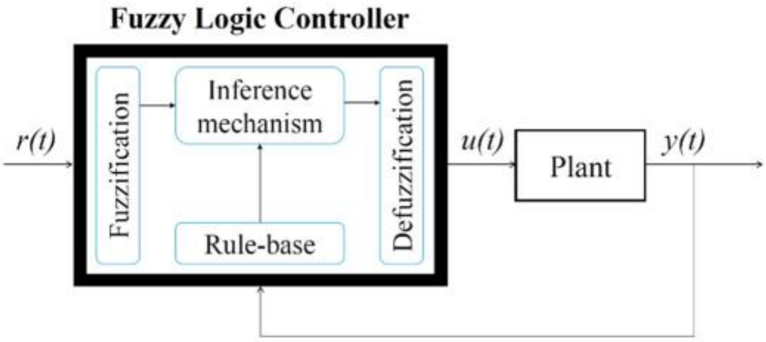

Figure 5: Fuzzy logic controller system block diagram

The structure of a fuzzy logic controller is shown in Figure 5. The design of a fuzzy logic controller includes the following four steps:

1, Blur: In this step, sharp inputs are converted into blur values.

2) Rule design: In this step, the fuzzy output truth values are calculated.

3) Calculation: In this phase, the necessary control actions are calculated.

4) De-blur: In this step, the blurred output is converted back to clear values.

The main steps involved in designing a fuzzy logic controller have been examined. These include, identification of input and output variables, a knowledge base, fuzzy inference inference, and a defuzzification procedure.

3.2.2 Design of fuzzy logic controller

Fuzzy control is the proposed method to overcome the problem of braking system [18, 20]. Mamdani fuzzy logic controller with two inputs and one output is designed. It is developed with two inputs which are the misalignment value between the desired slip and the actual slip λ_{error} and the derivative of the misalignment value between the desired slip and the actual slip $\frac{d\lambda_{error}}{dt}$, respectively described as follows:

$$\lambda_{error} = \lambda - \lambda_{target}$$
$$\frac{d\lambda_{error}}{dt} = \frac{\Delta\lambda_{error}}{\Delta t} \tag{18}$$

The output is the expected difference in brake pressure Δp.

All member functions of input language variables and output language variables are taken as triangular form

All inputs and outputs are divided into five fuzzy subsets: [NB, NS, ZO, PB, PS] (meaning large negative, small negative, 0, small positive, and large positive, respectively). The fuzzy rules are listed in Table 2.

Table 2: Fuzzy rules for ABS braking system

Δp	λ_{error}					
$\frac{d\lambda_{error}}{dt}$		PB	PS	ZO	NS	NB
	PB	NB	NB	NB	NS	ZO
	PS	NB	NB	NS	PS	PS
	ZO	NB	NS	ZO	PS	PB
	NS	NS	NS	ZO	PB	PB
	NB	NS	NS	PS	PB	PB

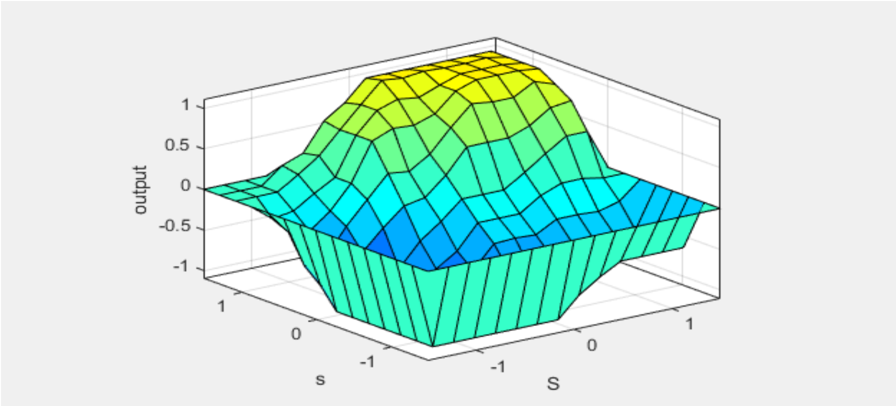

Figure 6: Surface view of the rules of the second fuzzy controller

Figure 6 provides a surface view of the rules of a fuzzy logic controller.

- 1st preprocessing coefficient of the input signal $\frac{d\lambda_{error}}{dt}$(S), select equal to 1.5 ie there are fluctuations between -1.5 and 1 . 5 m.

- 2nd preprocessing coefficient of the input signal λ_{error}(s), select equal to 1.5 ie there are fluctuations between -1.5 and 1 . 5 m.

- Post-processing coefficient of the output signalΔp (output), choose equal to 1 .5 which means there is internal fluctuation about -1 .5 to 1 .5 m.

3.3 The brake system uses a PID controller

The second approach of a braking system with ABS is to implement a PID control method. PID - Proportional Integral Derivative controller (PID - Proportional Integral Derivative controller) is a general control loop (controller) feedback mechanism widely used in industrial control systems - PID controller is the most used controller among feedback controllers and only applies to SISO systems based on the feedback principle.

$$U(s)= K_p + \frac{K_I}{s} + K_D \quad (19)$$

Method to select PID coefficient using Ziegler - Nichols method. This is considered the most effective and most commonly applied method.

Applying the Ziegler – Nichols 2 method we have: The coefficients K_P ,K_I ,K_D need to find are: K_P =100; K_I =K_P /T_I =692; K_D = T_D *K_P =3.6.

4. Results and conclusion

In this paper, two criteria to evaluate the system's performance are distance and braking time, which are investigated from the start of braking until the vehicle stops without taking into account the driver's reaction time. The wheel slip angle is assumed to be zero, i.e. only straight driving on a uniform flat road surface is used. Air resistance, aerodynamics and suspension vibrations are ignored. The input parameters used in the study are listed in table 1. The initial speed chosen is 28 m/s. Different control methods and parameters are used in different simulation cases and the results are compared and discussed.

Table 1 Input parameters of the simulation process

Symbol	Parameter	Treatment
m	Mass (Kg)	360
r_w	Wheel radius (m)	0.32
g	Gravitational acceleration (m/s ^{2})	9.81
v_0	Initial speed (m/s)	28
Kf	Force and torque	1
I	Rotational inertia of the wheel (kg.m ^{2})	5
Pbmax	Maximum torque (Nm)	1800
Ctrl	Control variable	1 or 0

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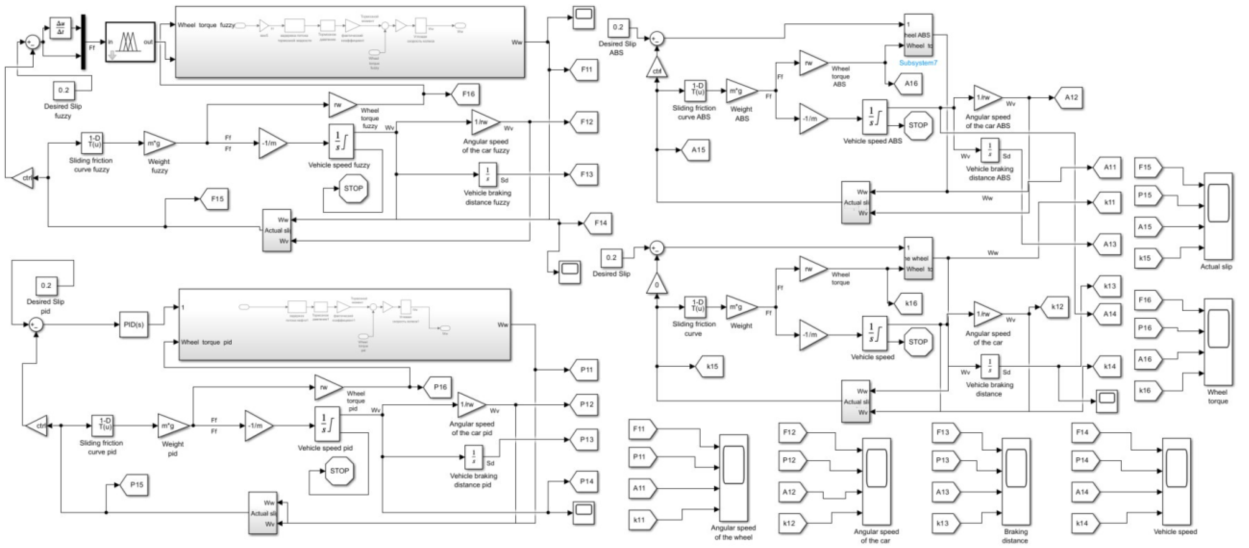

Figure 7: Brake system simulation model on Matlab/Simulink software

Result

The Simulink simulation will run for 05 seconds. Simulation results of the automatic braking system using the Fuzzy Logic controller are shown by typical graphs for the braking system.

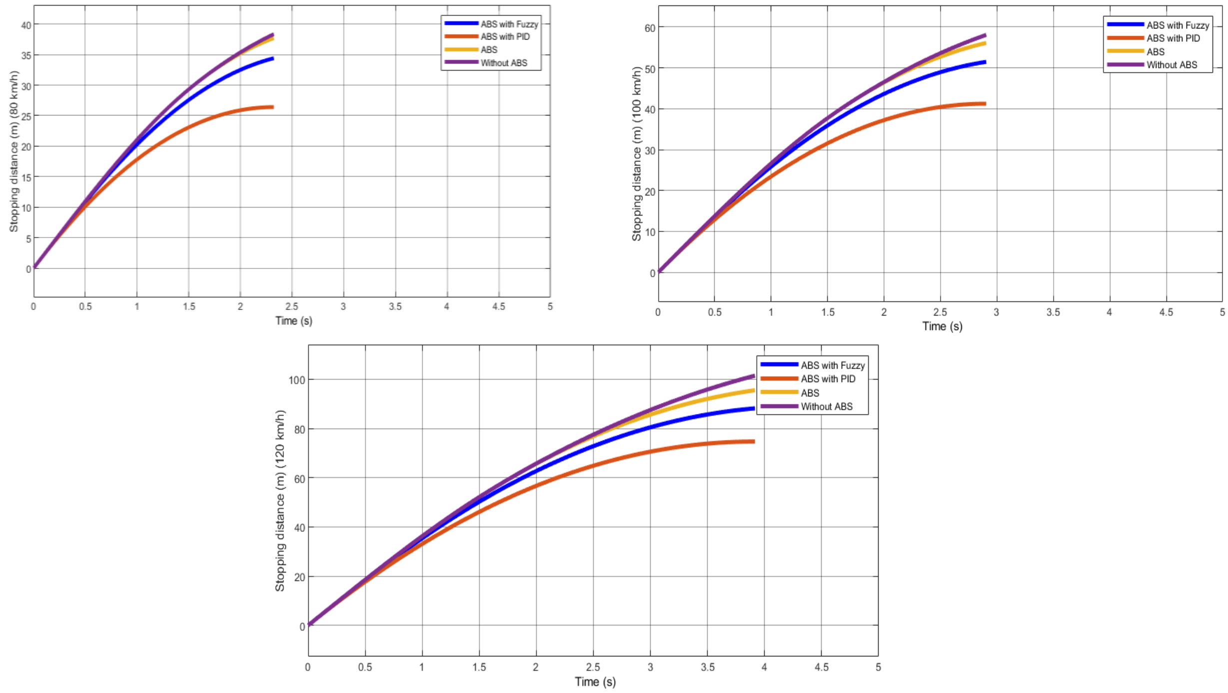

Figure 8: Stopping distance with different speed ranges

The graph shows the distance and stopping time corresponding to 4 cases. With an initial speed of 80 km/h, the system using ABS and not using ABS still has no obvious difference when the stopping distance is 37.5 m and 38 m in about 2.3 seconds, respectively. Meanwhile, with the braking system using PID, the system gives clearer results when with 2.3 seconds, the vehicle's stopping distance is 26 m

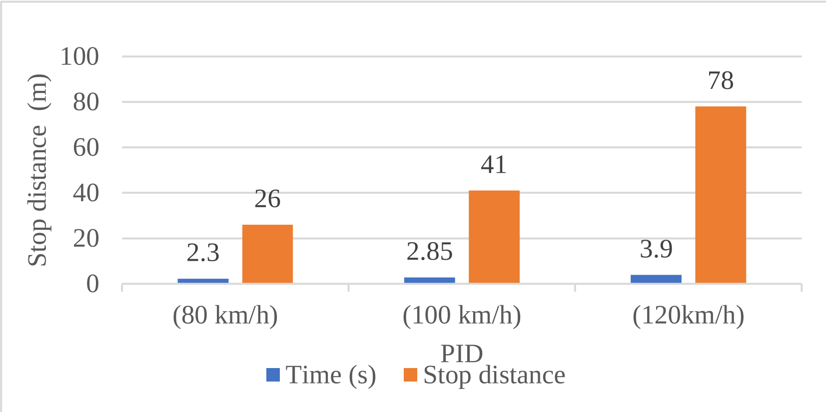

Figure 9: Comparison of stopping time and distance using PID controller

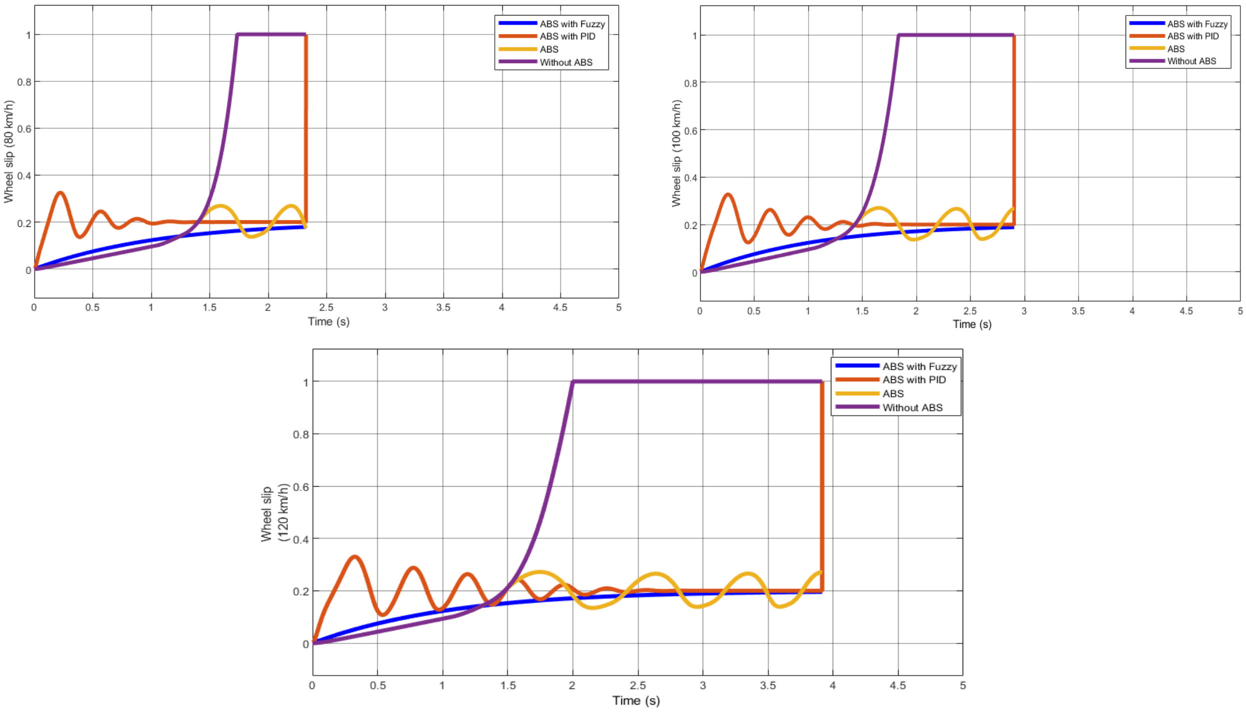

Figure 10: Variation of slippage during braking with different speed ranges

The graph shows that when the vehicle decelerates, the slip value with the system not using ABS will gradually approach the value 1, meaning the wheel speed is 0. Meanwhile, with the remaining 3 systems, the value always revolves around the desired value of 0.2 and especially with the brake system using a PID controller, the value fluctuates gradually and reaches the value 0.2 after 1.7 seconds and maintains that state until 2.9 seconds. then the pointer returns to a value of 1, meaning the car is stopping.

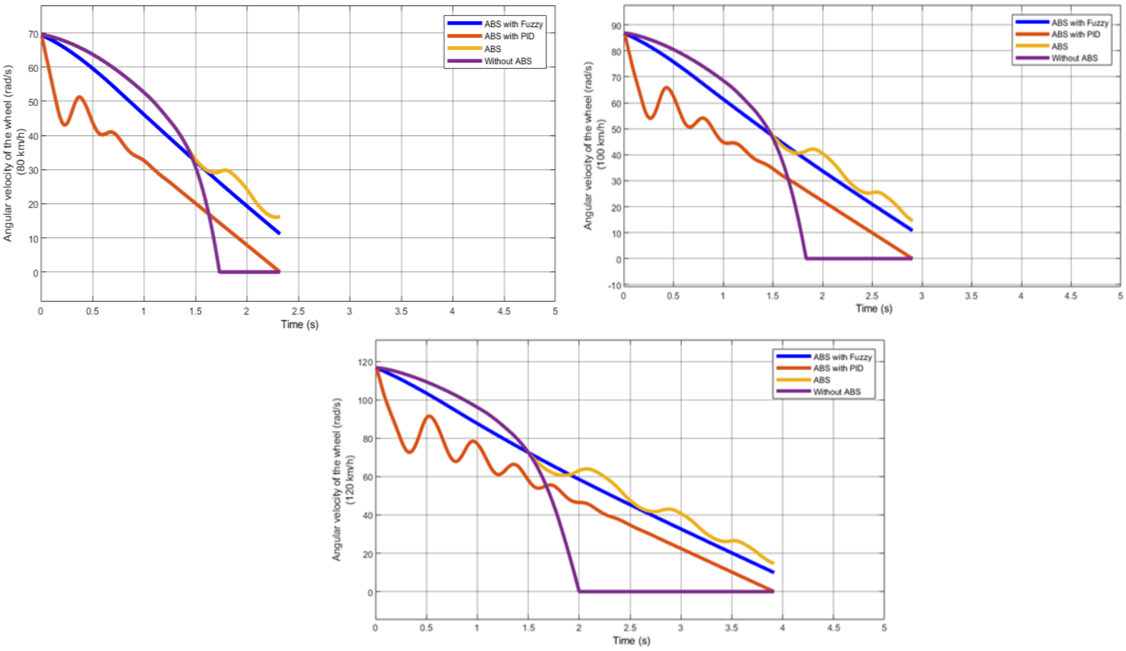

Figure 11: Angular velocity of the wheel with different speed ranges

Wheel speed is continuously controlled to prevent the wheels from locking. The vehicle speed and wheel speed both return to 0 after 2.92 seconds for the brake system using a PID controller. The ABS brake system along with the braking system uses a fuzzy logic controller and PID to synchronize vehicle and wheel speeds before the vehicle stops or steers to avoid skidding. The controller monitors the vehicle speed and adjusts the wheel speed to synchronize with the vehicle speed before the vehicle stops as shown in Figure 11 and Figure 12.

The vehicle's stopping distance has been reduced to 42 m in 2 .92 seconds to avoid a collision as shown in Figure 13 for the ABS braking system using a PID controller. This is the best value compared to the other 3 brake system use cases. For the braking system using the Fuzzy logic controller, it was reduced to 52 m in 2.92 seconds, 56 m for the ABS braking system and 58 m for the braking system without using a control system.

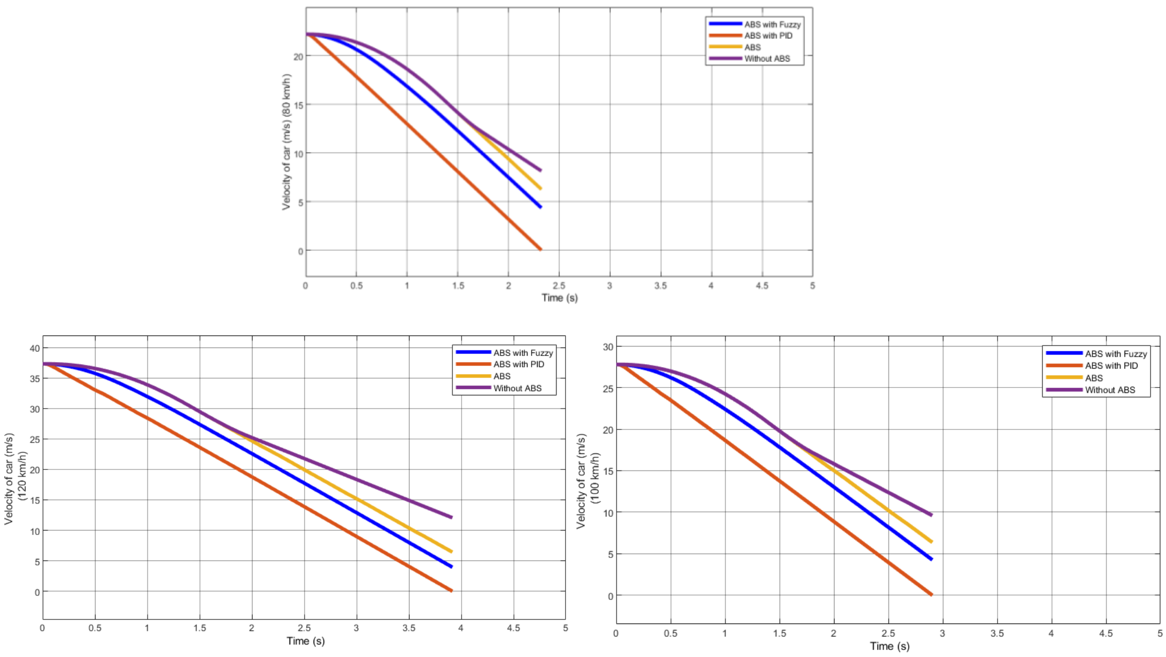

Figure 12: Vehicle speed with different speed ranges

True to the specifications, the author simulated the system with an initial vehicle speed of 28 m/s^2 and the system decreased to 0 (corresponding to the vehicle coming to a complete stop) in 2.92 seconds. This is the fastest braking time of the four systems using a PID controller with ABS brakes.

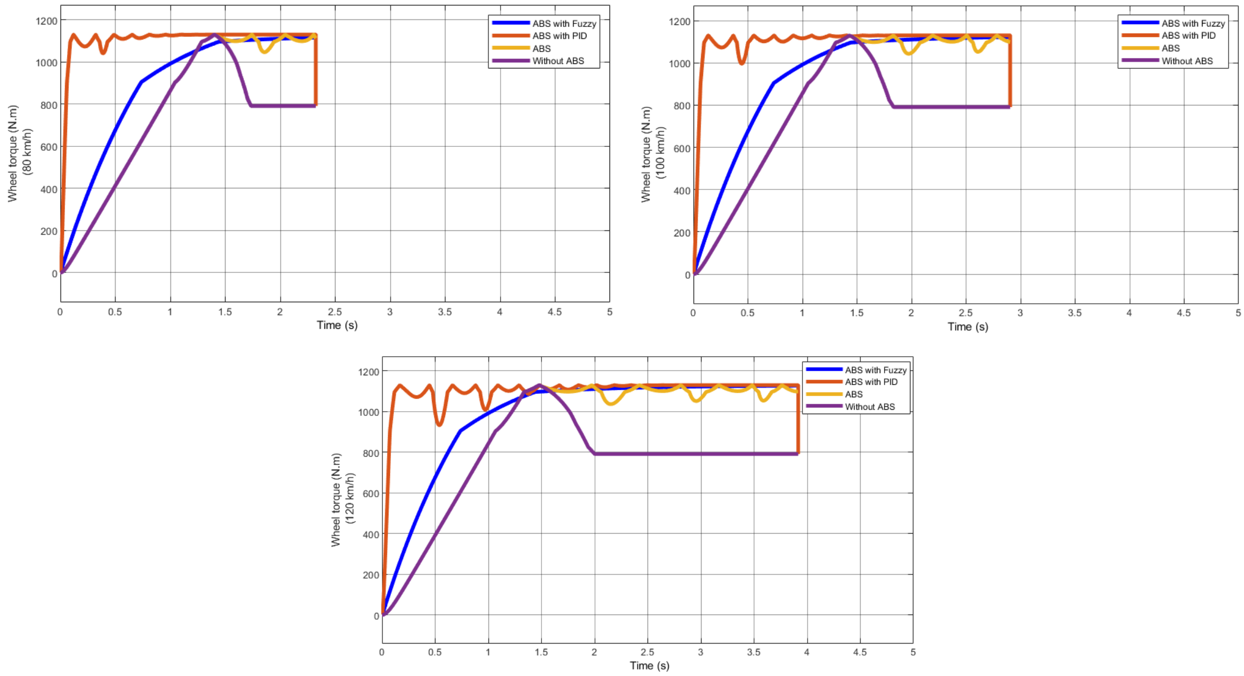

Figure 13: Wheel torque with different speed ranges

Figure 13 clearly shows the working performance of the ABS braking system using the PID controller when in just 0.1 second, the system's torque reached a value of 1120 Nm and the oscillation gradually damped and reached the value is 800 Nm when the vehicle stops with a value of 2.92 seconds.

5. Summary

This article focuses on analyzing the performance of the brake system with 4 systems: the brake system without ABS, the ABS brake system, the brake system using a fuzzy logic controller and the brake system using a controller. PID control simulated on Matlab/Simulink software. For systems using Fuzzy logic controllers, the simulation is based on a fuzzy logic rule table, while for ABS braking systems using PID controllers, the Ziegler-Nichols 2 method combined with simulink is used to Select PID coefficient. Simulation results have proven that the performance of the brake system using the PID controller gives better results than the remaining systems. The system is well suited for tight parking spaces, heavy traffic conditions, emergency situations and restricted areas. The simulated system provides more reliable and stable results when using ABS system applying PID controller and will be accepted by consumers.

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