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Fuzzy Control of Anti-Lock Braking System for the Modern Cars

NASERALINABE[1] , ALMUKHTAR AHMED[2]
[1]Faculty of Education, Zintan University, Zitan, Libya, Lecturer, Dep Of Math. Faculty Of Education, Zintan-Libya ,
[2]Faculty of Engineering, Sabratha University, Sabratha, Libya, Assist.Prof,Dept.of ELE &ELEC Eng,Faculty of Eng,Sabratha-Libya

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Abstract:- Due to the strength of modern cars and their lightness in weight compared to relatively old cars, manufacturers must consider the safety of passengers through the brakes. Therefore, anti-lock braking systems are used for these modern cars to prevent the wheels from locking up after applying the brakes. The car model has a non-linear shape. The control unit shall provide the tuned torque necessary to maintain the optimum value of wheel slip. In this paper to instruct fuzzy PID controllers to improve performance control of anti-lock brake systems compared to conventional PID controllers. An improved anti-lock braking system(ABS) that uses a vehicle quarter model and brake actuator. The car model is derived and simulated linearly towards. three types of controller: relay controller, genetically tuned linear PID and fuzzy PID-type controller. The quality of the anti-lock braking system is assessed in the Matlabsystem by the braking distance and the longitudinal slip coefficient of the vehicle. The fuzzy regulator showed the best characteristics for the anti-lock system model, reducing the braking distance by up to 10% compared to a conventional PID and by more than 30% compared to a relaycontroller. Practical significance: the proposed control algorithm is promising for implementation in an anti-lock system in real time.

***Keywords**:- Anti-Blocking System, Fuzzy Logic Controller, PID Controller, Genetic Algorithm.*

I. INTRODUCTION

In modern automation systems , when developing systems Fuzzy logical control is used more and more widely for managing complex technical objects. One of the difficult practical tasks, where the use of fuzzy logic controllers (FLCs) showed goodefficiency is the task of designing automotive anti-lock braking systems(ABS).

The development of efficient ABS is one of the main conditions for improving the safety of road transport. Emergency application of the brakes to stopping the car or reducing its speed can lead to the opposite the result - the wheels are blocked and lose traction, and the carkeeps speed and stops obeying the steering wheel. The first ABS , which appeared in the automotive industry in the 60s. XX century, built on analog processors, were expensive and unreliable [1, 2]. Modernbuilt-in automotive microprocessor systems allow implementing complex control algorithms, including those based on fuzzy logic.

FLCs is based on fuzzy rules , Thus, FLC can be considered as a kind of expert systems in which knowledge is explicitly represented in the form of rules. When designing the ALBS also uses this approach. Setfuzzy rules allows you to describe the nonlinear control law and improve the quality of the ABS ([3–5]) .

However, more opportunities are provided by the search optimization of FLC, since a person, due to his limited psychophysical capabilities, is an unreliable source of information when analyzing fast processes at the moment of braking a car. The complexity of the FLC optimization problem requires the use of global search methods, such as the genetic algorithm or the particle swarm method [6–8]. These methods use the objective function as the discrepancy between a given reference process and the output of the simulation model for a specific set of parameters. Parameters change during optimization regulator, and the model parameters remain unchanged. Thus, the fewer adjustable parameters the FLC has, the easier the optimization problem is. In this paper, when designing an ABS, we consider the genetic optimization of a fuzzy PID-type controller, which is a 3-channel structure with a piecewise linear approximation of the nonlinear function of each channel [9–11].

- *Mathematical description for braking process:*

When constructing a description of the ABS of a car , the following assumptions are usually used [2]:
- the dynamics of the car wheels is identical;
- the mass of the car is evenly distributed over all four wheels;
- the influence of the transmission and vehicle suspension is not taken into account.

Thus, a one-wheeled car model can be considered during braking (Fig. 1). The figure uses the following notation:
M_T - braking torque, N.m ;
F_x– longitudinal component of the contact force of the wheel, N ;
v- absolute vehicle speed, m / s;
ω - angular speed of the wheel, rad / s;
F_N - reaction forcesupports (normal force), N.
The car motion equations are:

$$\begin{cases} J\dfrac{d\omega(t)}{dt} = F_x(t)r - M_T(t) \\ m\dot{v}(t) = -F_x(t) \end{cases}; \qquad (1)$$

Where : J is the moment of inertia of the wheel, kg.m2;r – radiuswheels, m.Longitudinal component of contact forcedefined by the expression :

$F_x = \mu(s(t))F_N$ …………………… (2)

where : μ is the coefficient of road friction ; s - longitudinal slip.
Normal force is obtained by the formula :

$F_N = mg$ …………………………….. (3)

Where : m is the mass of the car reduced to one wheel (m = M / 4, where M is the mass of the car) , g - acceleration of gravity.

Wheel slip is determined by the formula :

$$s(t) = \frac{v_s(t)}{v(t)} = \frac{v(t) - v_\omega(t)}{v(t)} = \frac{v(t) - \omega(t)r}{v(t)}$$

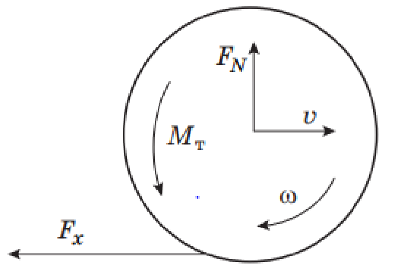

Fig. 1. Braking wheel model

Therefore :

$$\omega(t) = \frac{v(t)}{r}\,(1 - s(t))$$

or s = 0, perfect adhesion is observed with the road, no slipping.

When : s = 1 wheel is blocked, uncontrollable controlled sliding. The value of μ (s) is influenced by many factors:road condition, weather conditions, condition tires, vehicle speed. Approximate dependencies bridge μ (s) for different road conditions coatings are shown in Fig. 2.An analytical description can be used. Reduction of the coefficient of road friction with the help the formulas [12]

$$\mu(s) = \alpha(1 - e^{-bs} - cs) \dots\dots\dots (5)$$

where a, b and c are coefficients depending on the state of the road surface.

For example, for dry asphalt the values of coefficients: a = 1.28, b = 23.99 and c = 0.52. To calculate the slip value you need to have information about the angular and linear wheel speed. Measuring the angular velocity of the forest with sensors is enough a simple task. However, accurately measure the absolute fierce car speed in real time nor difficult, which leads to the need to use use slip estimates. In [13], to describe the coefficient of friction, the formula is used, taking into account vehicle speed:

$$\mu(s, v) = (c_1(1 - e^{-c_2 s}) - c_3 s)e^{-c_4 s v} \dots\dots (6)$$

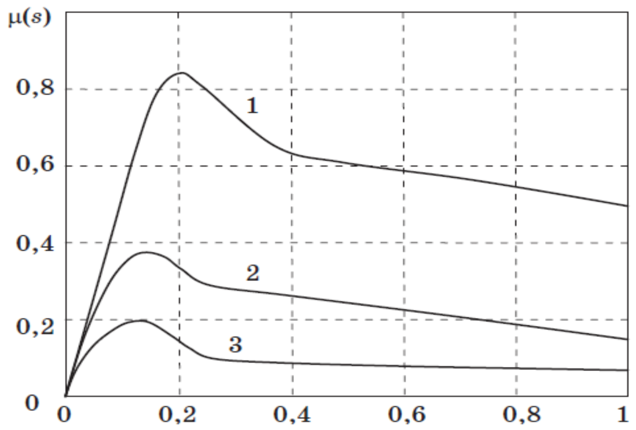

Figure: 2. Dependence of the road demand coefficient longitudinal slippage; before- skin cover: 1 - dry, 2 - wet, 3 - slippery (icy) .

- Parameters for calculating the road coefficient friction :

Roadbed	C_1	C_2	C_3	C_4
Dry asphalt	1.029	17.16	0.523	0.03
Dry concrete	1.197	25.168	0.5373	0.03
Snow	0.195	94.129	0.0646	0.03
Ice	0.05	306.4	0	0.03

The parameters included in (6) are given in the table face. Consider the derivative of longitudinal slip:

$$s(t) = \frac{-r}{v(t)}\omega(t) + \frac{r\omega(t)}{v^2(t)}v(t)$$

$$= \frac{-r\omega(t) + (1 - s(t))v(t)}{v(t)} \dots\dots (7)$$

From (1) - (3) :

$$\omega(t) = \frac{mg\mu(s(t))r - M_T(t)}{J} \dots\dots\dots\dots (8)$$

Substituting (8) into (7), we can write the system equations describing the dynamics of the wheel at braking :

$$\begin{cases} \dot{s}(t) = -\dfrac{1}{v(t)}\left(\dfrac{1-s(t)}{m}+\dfrac{r^2}{J}\right) mg\mu(s(t)) + \\ +\dfrac{r}{v(t)J}M_T(t); \\ \dot{v}(t) = -g\mu(s(t)). \end{cases} \qquad (9)$$

The braking torque can be described by :

$$M_T(t) = \begin{cases} kP(t), & kP(t) < M_{\max}; \\ M_{\max}, & kP(t) \geq M_{\max}, \end{cases} \qquad (10)$$

where k is the braking constant; P - pressure, generated by the braking system when pressing down pads to the brake disc: M_{max} - max-minimum pressure in the brake system.

More realistic braking torque can bedescribe the transfer function with delay [14]:

$$\frac{M_T(s)}{P(s)} = e^{-\tau s}\frac{ka}{s+a}. \qquad (11)$$

Equations (5), (6) and (9) - (11) represent a model of vehicle dynamics during braking. When carrying out computational experiments, we will consider a passenger car with the following parameters: initial speed v_0 = 100 km / h; mass (given on one wheel) m = 375 kg; wheel radius r = 0.32 m; wheel moment of inertia J = 1.7 kg□m2; maximum braking torque 2500 N.m .

II. ANTILOCK BRAKING SYSTEM MODEL

A typical ABS consists of a central microprocessor, four wheel speed sensors (one for each wheel), and two or four hydraulic or pneumatic valves in the brake control circuit. The operation of wheel sensors is based on the principle of electromagnetic induction. When the wheel rotates, the teeth and cavities of a special rotor pass by the sensor and induce an electrical signal in the sensor winding, the frequency which is proportional to the angular speed of the wheel andthe number of teeth on the rotor.

To keep the vehicle straight after braking starts, the microprocessor analyzes the speed of each wheel. If a particular wheel rotates much slower than others, then the pressure in the corresponding brake cylinder decreases.

To control the valves, pulse-width modulation (PWM) can be used, which generates a sawtooth signal with a period T (Fig. 3), with which the current value of the control signal is compared. As a result of the comparison, the brake valve switches to brake mode (ON) or to release mode (OFF) . The hydraulic braking system as well as the microprocessor create some time delay, so it is incorrect to use the slip coefficient value obtained from the system output to calculate the error. It is necessary to predict the future value of the slip coefficient in real time and use it to control the error [15].

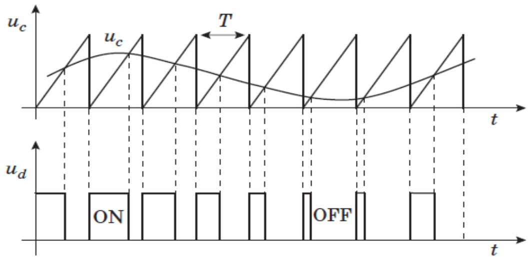

Figure: 3. Using PWM

Slip Coefficient Observer Model can be constructed by writing (4) in the form:

$$s(t)v(t) = v(t) - r\omega(t). \qquad (12)$$

By differentiating (12) with respect to time :

$$\dot{s}(t) = \frac{1}{v(t)}\left(\left(1-s(t)\right)\dot{v}(t) - r\dot{\omega}(t)\right). \qquad (13)$$

Replace the derivatives with finite differences:

$$\dot{s}(t) \approx \frac{s(k+1)-s(k)}{\Delta t}; \quad \dot{v}(t) \approx \frac{v(k+1)-v(k)}{\Delta t}; \quad \dot{\omega}(t) \approx \frac{\omega(k+1)-\omega(k)}{\Delta t},$$

Where k is the moment in time; Δt - discrete interval Then expression (13) is transformed into the formula to predict slip coefficient:

$$s(k+1) = s(k) + \frac{\Delta t}{v(k)} \times \\ \times\left(\left(1-s(k)\right)\left(\frac{v(k+1)-v(k)}{\Delta t}\right) - r\left(\frac{\omega(k+1)-\omega(k)}{\Delta t}\right)\right).$$

The ABS model takes the form shown in fig. 4. During the simulation, three variations were compared anta of the control law.

1.Relay control:

$$u_c(t) = \begin{cases} P_{\max}, & e(t) > 0; \\ 0, & e(t) \leq 0. \end{cases}$$

2. PID controller with saturation:

$$u_c(t) = \begin{cases} u = k_p e(t) + k_d\dfrac{de(t)}{dt} + k_i\int e(t)dt, & u < P_{\max}; \\ P_{\max}, & u \geq P_{\max}; \\ 0, & e(t) \leq 0. \end{cases}$$

3FLCs with saturation:

$$u_c(t) = \begin{cases} u = F_p(e(t)) + F_d\left(\dfrac{de(t)}{dt}\right) + F_i\left(\int e(t)dt\right), & u < P_{\max}; \\ P_{\max}, & u \geq P_{\max}; \\ 0, & e(t) \leq 0. \end{cases}$$

Here : k_p, k_d, k_i are the adjustable coefficients of the PID controller; F_p, F_d, F_i are tunable nonlinear functions that approximate a fuzzy control law [9–11].

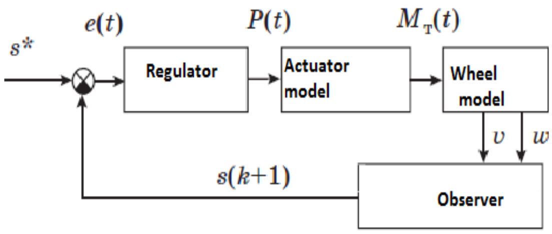

Figure: 4. ABS model with coefficient observer slip

A genetic algorithm was used to tune the PID controller and the PID type FLC. The genetic adjustment algorithm of the FLC is described in [11].

III. SIMULATION RESULTS

The block diagram of the experiment in MatLab Simulink is shown in **Fig. 5**. Three control options were investigated: relay controller, PID controller, and PID-type FLC. Transient processes of changes in vehicle speed during braking for different governors are shown in Fig. 6, a – c. The structure of the FLC PID-type after training is shown in

Fig. 7. The low-pass filter at the output of the regulator serves to smooth out sharp jumps in the control signal.

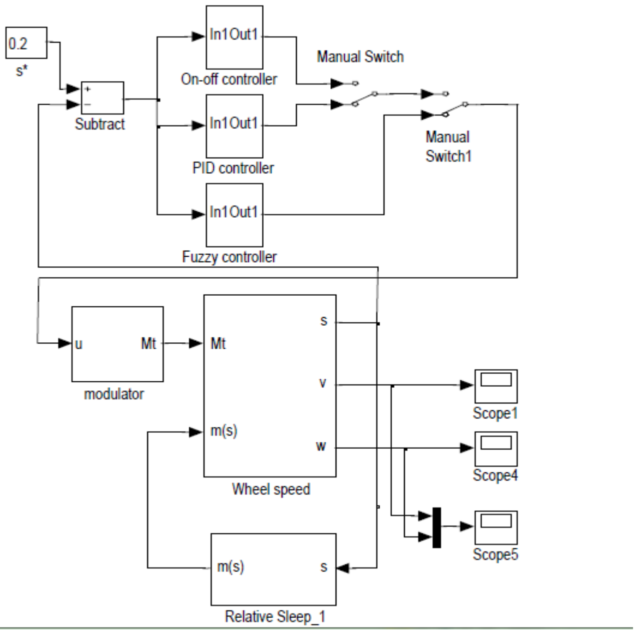

Figure: 5. Investigation of various control laws in the ABS

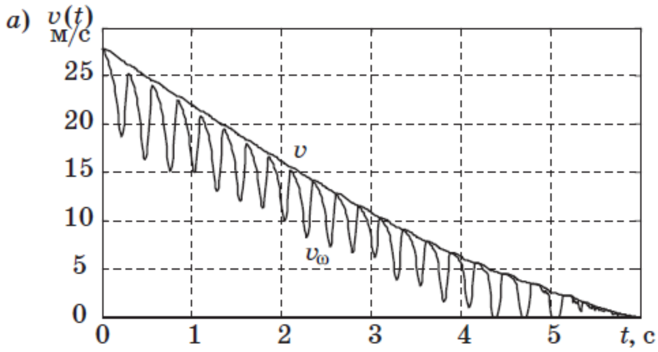

Fig : 6 (a). Transient process with relay control law

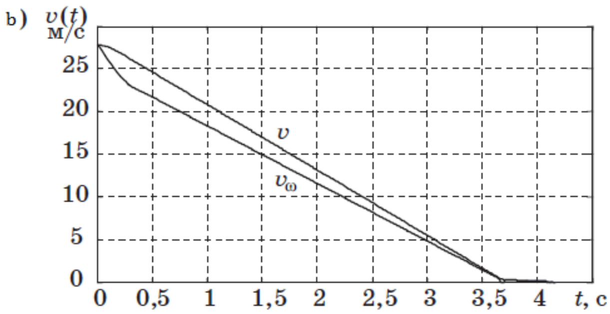

Fig: 6(b)The transient process under the control of the PID controller

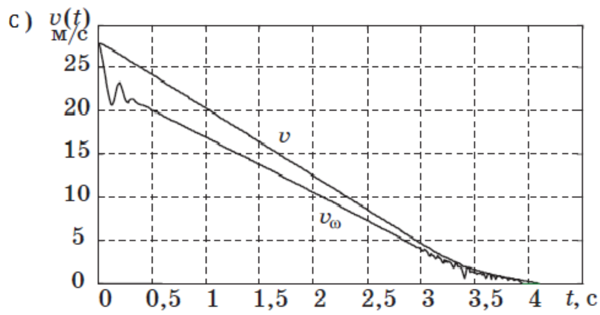

Fig: 6(c) The transient process under the control of FLC controller

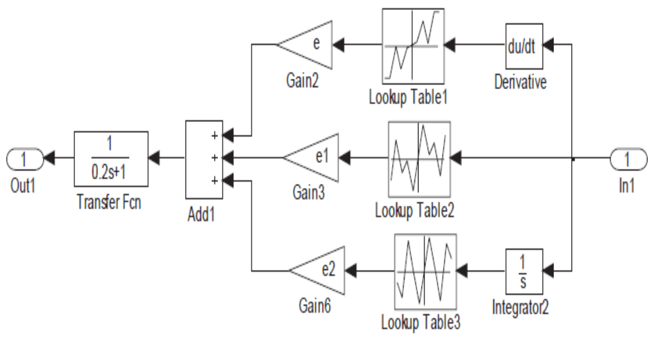

Figure: 7. Fuzzy PID-type controller after learning

A comparison of the control signals generated by the PID controller and the FLC during transient processes is shown in (Fig. 8, and in Fig. 9) braking distance for different control laws. Thus, the simulation results demonstrate a significant advantage of the PID-type nonlinear FLC over alternative controllers.

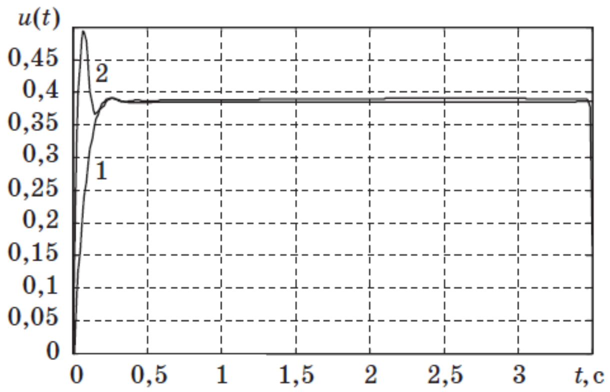

Fig: 8. Control signals: 1 - PID controller;
2 - PID type FLC

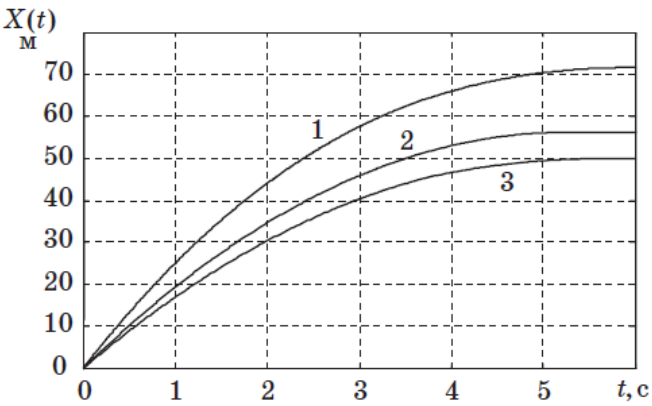

Figure: 9. Braking distance: 1 - relay regulator;
2 - PID controller; 3 – FLC PID-type

IV. CONCLUSION

When simulating the operation of the ABS, a one-wheel model of a car was considered, the main parameters of which are the mass of the car, the radius and moment of inertia of the wheel, as well as the maximum braking torque. The driving conditions of the vehicle on a specific road surface are set by the dependence of the road friction coefficient (slip coefficient) on wheel slip μ (s).This dependence can be set analytically for different typical conditions of the road surface. For a more accurate description of the slip coefficient, it is necessary to take into account the vehicle speed. Since the hydraulic braking system and microprocessor create some time delay, it is not correct to calculate the error use the current value of the slip coefficient. It is necessary to predict in real time the future value of the slip coefficient using the slip coefficient observer. Three control options were investigated: relay controller, as well as a genetically tuned linear PID controller and a non-linear PID type FLC . Computational results experiments have shown that a relay-type regulator is significantly inferior to FLC and PID regulators in terms of the braking distance. FLC provides a shorter braking distance compared to a linear PID controller approximately by 10% and more than 30% compared to the relay controller. The proposed fuzzy control algorithm is promising for implementation in the ABS system in real time.

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