Fuzzy Control Method Research on Vehicle ABS Braking of Icy Pavement

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\textbf{Abstract.} Building Simulink module connection, then form a completely ABS simulation model, respectively on icy pavement, respectively simulation the braking under different velocity combine with parameters of HongGuang models, the industry company of Wuling automobile in Liuzhou. From the simulation result we can see that when the car with an ABS braked, the wheel wouldn’t lock when there is an Anti-lock Braking System with fuzzy controller work in a car. It can help to achieve a good braking effect.

\textbf{Introduction}

Anti-lock Braking System (ABS for short) \cite{1} is the key to the driving safety. Most drivers will crush to death the brake pedal immediately to reach braking and secure parking in an emergency. If the front wheels is still rolling before the rear wheels lock and slip, even the car subjected to small lateral disturbance force, it will also have a side slip (spin) phenomenon \cite{2}. These are easily cause a serious accident when cars braking. Automotive anti-lock braking system (Anti-lock Braking System, referred to as ABS) can improve vehicle safety performance, but it is difficult to establish a precise mathematical model for cars with higher nonlinear braking process. In this paper, using MATLAB software to build a simulation model of 1/4 of the vehicle\cite{3} and to establish ABS fuzzy controller, using MATLAB / Simulink to simulate the ABS, on different friction coefficient road surfaces and with different speed.

\textbf{Mathematics Methods}

\textbf{Car Model of Single Wheels.}

To simplify the research problem, the system uses a single wheel vehicle model \cite{4} \cite{5} \cite{6}.

In this paper, use a single wheel model to simulate the straight-line braking and to study the control logic of vehicle anti-lock. Simplified system model, ignoring air resistance and rolling resistance of the wheel, the following equation can be given by:

The dynamic equation of the vehicle \cite{7}:

$$M \ddot{v} = -F_s$$ \tag{1}

The motion equation of Wheels:

$$I \ddot{\omega} = F_s R - M_b$$ \tag{2}

The frictional force in longitudinal of wheels:
\[ F_y = N\mu \] (3)

The above equations: \( M \) is vehicle quality; \( v \) is vehicle speed; \( F_f \) is wheel friction; \( I \) is inertia of the wheel; \( R \) is rolling radius of the wheel; \( \omega \) is angular velocity of the wheel; \( \mu \) is the friction coefficient between the wheels and the ground; \( F_n \) is the normal applied force in reverse of wheels to the ground.

**Tire Model**

Based on the purpose of the study, use bi-fold models to simulate three typical curve of the road, and used in the simulation model of automotive anti-lock braking system. On the three different road, optimum slip ratio, the peak adhesion coefficient, the slip rate of 1, the adhesion coefficient values were: dry concrete pavement (0.2,0.9,0.75), wet asphalt pavement (0.2,0.78,0.5 ) , icy pavement (0.1,0.1028,0.07). According to the mathematical expression of bilinear model [8][9][10] simplified tire model to obtain the following expression:

\[
\begin{cases}
  u = \frac{u_h}{S_{opt}} \cdot S & \text{if } S \leq S_{opt} \\
  u = \frac{u_h - u_g S_{opt}}{1 - S_{opt}} - \frac{u_h - u_g}{1 - S_{opt}} S & \text{if } S > S_{opt}
\end{cases}
\] (4)

Where: \( S \) is slip rate; \( u \) is longitudinal friction coefficient; \( u_h \) is peak adhesion coefficient; \( u_g \) is adhesion coefficient for the slip rate of 1; \( S_{opt} \) is optimum slip ratio.

**Braking System Methods**

**Braking System Analysis**

Brake model refers to the relationship between the braking force and braking hydraulic [11]. In order to facilitate the research of control algorithm, The effect from of the lagging brake is ignored. The equation of brake system is:

\[ T_b = k_p \cdot p \] (5)

Where: \( T_b \) is brake torque of brake; \( k_p \) is brake factor of brake; \( p \) is brake pressure of brake.

Hydraulic mechanism, is composed of electromagnetic valve, spring damping system:

A solenoid valve link:

\[ \frac{K}{T_k \cdot S + 1} \] (6)

With a spring-damper system:

\[ \frac{1}{T \cdot S + 1} \] (7)
An integral section:

\[ \frac{1}{s} \]  

(8)

Whereby the transfer functions of hydraulic system is:

\[ G(s) = \frac{K}{S(T_s \cdot S + 1)(T \cdot S + 1)} \]  

(9)

So the solenoid valve is excluding in the simulating, taking inertia parameters \( T = 0.01 \text{s}, K = 100 \). Can be obtained from the above analysis, the hydraulic system transfer function is:

\[ G(s) = \frac{100}{s(0.01s + 1)} \]  

(10)

**Design of Fuzzy Controller**

The first is to determine the input and output variables of fuzzy controller [12] [13]. In this paper, take slip ratio error and the rate of change of slip error as fuzzy controller’s input, and take brake pressure as the output of fuzzy controller, and design an ABS fuzzy controller with double inputs and single output.

Due to \( E \) is change in the interval \([0, 1]\), if the desired setting of \( E \) is 0.2, then \( E \) is the change in the interval \([-0.2, 0.8]\), \( EC \) desirable interval \([-1, +1]\), \( U \) interval is \([-1, 1]\), and then converted to a standard interval \([-6, 6]\). Input and output are divided into seven membership function [14], namely PL is positive large, PM is positive middle, PS is positive small, ZE is zero, NS is negative small, NM is negative middle and NL is negative large.

Use fuzzy conditional statement to design fuzzy control rules "If \( E \) and \( EC \) then \( U \)" to represent.

**ABS Anti-lock Braking System**

In MATLAB / Simulink to built the corresponding simulation system, and to complete the ABS simulation model connection, so simulation diagram of ABS system as follows in Fig. 1.

![Figure 1. ABS system simulation diagram.](image)

**Simulation and Results**

This article was selected models of Hongguang series, which Liuzhou Wuling Automotive Company models, but also the first home Business Series models of Wuling. It is the 2010 hongguang luxury
series of Wuling Company with 1.4L [15,16]. Specific parameters such as: vehicle mass 1260kg (1/4 vehicle mass of 315kg), the wheel radius 0.298m, vehicle inertia 13.99kg.m$^2$, the maximum speed of 150km/h.

**On Icy Road**

The optimum slip ratio is set to 0.1, and were set speed of 15km/h and 30km/h, the tire model parameters: constant = 0.1064, constant1 = 0.0364, constant2 = 1.028, the simulation step is set to 0.01s. Running Simulation, results are obtained.

![Graphs](image)

Figure 2. ABS system with fuzzy control when $V_0 = 30km/h$.

![Graphs](image)

Figure 3. ABS system not working when $V_0 = 30km/h$.

By analyzing, induction and summarize about speed and wheel speed curve, slip rate curve and Braking distance curve, which from Fig. 2 and Fig. 3, can get the data in Table 1.
Table 1. The simulation data on icy roads.

<table>
<thead>
<tr>
<th></th>
<th>Braking time</th>
<th>Braking distance</th>
<th>When the wheel lock</th>
<th>Stend to be</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>On icy roads</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABS V=15km/h</td>
<td>4.6s</td>
<td>10.6m</td>
<td>nothing</td>
<td>0.1</td>
</tr>
<tr>
<td>ABS V=30km/h</td>
<td>8.68s</td>
<td>37.5m</td>
<td>nothing</td>
<td>0.1</td>
</tr>
<tr>
<td>Fuzzy V=15km/h</td>
<td>6.12s</td>
<td>13.4m</td>
<td>75ms</td>
<td>1</td>
</tr>
<tr>
<td>Fuzzy V=30km/h</td>
<td>12.09s</td>
<td>50m</td>
<td>90ms</td>
<td>1</td>
</tr>
</tbody>
</table>

From table 1 the simulation data on icy roads can be seen: when the model car running with the same speed, the braking time of car with ABS is smaller than without ABS, and ABS braking distance is short than ABS does not work, won't appear wheel lock phenomenon and the slip rate can be maintained at the optimum slip ratio range, close to the optimum slip rate of 0.1. When the model car with ABS running with different speeds, the higher speed, the more obvious of the ABS braking effect.

Conclusions

Whether in the icy pavement, wet or dry asphalt concrete pavement, when the ABS system with fuzzy control work, can prevent the wheels from locking in the process of vehicle braking, so that the slip rate can be maintained at the optimum range and shorten braking time and braking distance.

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