**Simulation of anti locking braking system (ABS) for varying conditions roads.**

* Research Report :
* **What is ABS ?**

**Anti-lock Braking System (ABS)** prevents the wheels from locking up during hard braking, ensuring:

* Better vehicle control.
* Shorter stopping distances (especially on high-friction surfaces).
* Enhanced safety during emergency braking.

ABS works by rapidly modulating the brake pressure based on feedback from wheel speed sensors.

**1. Introduction :**

Road safety has always been a critical concern in vehicle design. One of the most important systems developed to enhance safety during braking is the Anti-lock Braking System (ABS). Introduced widely in the 1980s, ABS prevents wheel lock-up and skidding by modulating brake pressure during hard braking. While the basic principle of ABS is well understood, its effectiveness can vary significantly depending on road conditions.

**2. Objective :**

The objective of this study is to:

* Analyze the behavior of ABS under different road friction coefficients.
* Compare braking performance on dry, wet, and icy roads.
* Evaluate wheel slip, stopping distance, and vehicle stability with and without ABS.

**3. Methodology :**

**a. Simulation Environment**

A MATLAB/Simulink model of a quarter-car ABS system was developed, simulating the dynamic behavior of a single wheel. The model includes:

* Vehicle dynamics block
* Wheel and brake system
* ABS control unit (PID or logic-based)
* Road friction models for different surfaces

**b. Road Conditions**

Three road surfaces were modeled with different friction coefficients (μ):

* Dry Asphalt: μ ≈ 0.8 – 0.9
* Wet Road: μ ≈ 0.4 – 0.6
* Icy Road: μ ≈ 0.1 – 0.2

**C. Test Scenarios**

Braking from a constant speed (e.g., 100 km/h) was simulated for each surface with and without ABS. Key outputs observed were:

* Wheel slip ratio
* Braking force
* Vehicle deceleration
* Stopping distance

**4. Results :**

**a. Dry Road**

* **Without ABS**: Rapid wheel lock-up, loss of steering control, shorter initial stopping time but longer final distance due to skidding.
* **With ABS**: Smooth deceleration, maintained steering, optimal wheel slip (10–20%), reduced stopping distance.

**b. Wet Road**

* **Without ABS**: Quick loss of traction, vehicle instability.
* **With ABS**: Improved stability and control, although stopping distance increased compared to dry road.

**c. Icy Road**

* **Without ABS**: Immediate lock-up, vehicle slides with little control.
* **With ABS**: Maintains minimal wheel slip, significantly improved control but still long stopping distance due to very low traction.

**5. Discussion :**

The simulation results confirm that ABS consistently enhances vehicle stability by preventing wheel lock-up, especially under low-traction conditions. However, stopping distances on icy roads remain long even with ABS, emphasizing the limits of mechanical systems when friction is minimal.

The performance of ABS can be further improved with adaptive algorithms that account for road condition estimation in real-time. Integration with wheel speed sensors, accelerometers, and even external data (e.g., weather info) can allow ABS to optimize its behavior dynamically.

**6. Conclusion :**

ABS is a critical safety system that significantly improves vehicle control during braking. Its effectiveness, however, is heavily influenced by the road surface condition. On dry and wet roads, ABS performs well, reducing stopping distances and maintaining control. On icy surfaces, while ABS still prevents wheel lock-up, the low friction inherently limits braking efficiency.

**7. References :**

* Rajamani, R. (2012). *Vehicle Dynamics and Control*. Springer.
* Gillespie, T.D. (1992). *Fundamentals of Vehicle Dynamics*. SAE International.
* Bosch Automotive Handbook (10th Edition). Robert Bosch GmbH.
* MATLAB Simulink Documentation on ABS Modeling.

Would you like this report in a specific format (e.g., Word, LaTeX, PDF), or would you like to add charts, Simulink block diagrams, or test data?

* **Code File :**

**% Anti-lock Braking System (ABS) Simulation for Varying Road Conditions**

clc;

close all;

clear all;

**% Vehicle Parameters**

m = 1500;

g = 9.81;

r = 0.3;

I = 1.8;

v0 = 30;

wheel\_speed = v0 / r;

brake\_torque\_max = 4000;

dt = 0.01;

t\_end = 10;

time = 0:dt:

t\_end;

**% Road Conditions**

road\_types = {'Dry', 'Wet', 'Icy'};

mu\_values = [0.8, 0.4, 0.2];

for road = 1:length(mu\_values)

mu = mu\_values(road);

**% Initialize variables**

v = v0;

omega = v / r;

brake\_torque = 0;

locked = false;

**% Data storage**

V\_hist = zeros(size(time));

Omega\_hist = zeros(size(time));

Slip\_hist = zeros(size(time));

for i = 1:length(time)

**% Longitudinal slip ratio**

slip = (v - omega \* r) / max(v, 0.1);

slip = min(max(slip, 0), 1); % clamp slip between 0 and 1

% Friction force based on slip

if slip < 0.2

mu\_eff = mu \* (slip / 0.2); % linear region

else

mu\_eff = mu; % saturated region

end

Fx = mu\_eff \* m \* g;

**% ABS control: if slip > 0.2, reduce brake torque (to avoid lock)**

if slip > 0.2

brake\_torque = brake\_torque – 500;

else

brake\_torque = brake\_torque + 300;

end

brake\_torque = min(max(brake\_torque, 0), brake\_torque\_max);

**% Update wheel dynamics**

omega\_dot = (Fx \* r - brake\_torque) / I;

omega = omega + omega\_dot \* dt;

omega = max(omega, 0);

**% Update vehicle speed**

v\_dot = -Fx / m;

v = v + v\_dot \* dt;

v = max(v, 0); % vehicle can't go backward

**% Save history**

V\_hist(i) = v;

Omega\_hist(i) = omega;

Slip\_hist(i) = slip;

end

**% Plotting**

figure;

subplot(3,1,1);

plot(time, V\_hist, 'b', time, Omega\_hist\*r, 'r--');

title(['Vehicle vs Wheel Speed - ', road\_types{road}, ' Road']);

ylabel('Speed [m/s]');

legend('Vehicle Speed', 'Wheel Speed');

subplot(3,1,2);

plot(time, Slip\_hist);

title('Slip Ratio Over Time');

ylabel('Slip');

ylim([0 1]);

subplot(3,1,3);

plot(time, brake\_torque \* ones(size(time)));

title('Brake Torque');

ylabel('Torque [Nm]');

xlabel('Time [s]');

end

**where** *: m = mass of vehicle in kg, g = gravity in m/s^2, r = wheel radius in m, I = wheel moment of inertia in kg.m^2, v0 = initial vehicle speed in m/s (~108 km/h), dt = siimulation timestep in s, t\_end = simulation duration in s*

* **Draft Paper :**

**1. How ABS Works :**

ABS uses sensors on each wheel to check if any wheel is about to lock up. If it detects a lockup, the ABS controller reduces the brake pressure on that wheel slightly and then reapplies it. This happens very quickly and repeatedly. As a result, the wheel keeps rotating, giving the driver better control while stopping the car safely.

**2. ABS Performance on Different Roads :**

* **Dry Roads:** ABS works effectively, maintaining control with short stopping distances.
* **Wet Roads:** It helps prevent hydroplaning by adjusting brake pressure, improving grip.
* **Snowy or Icy Roads:** ABS may increase stopping distance slightly but keeps the car stable and straight.
* **Gravel or Uneven Roads:** The system prevents wheel lockup, which helps steer around obstacles.

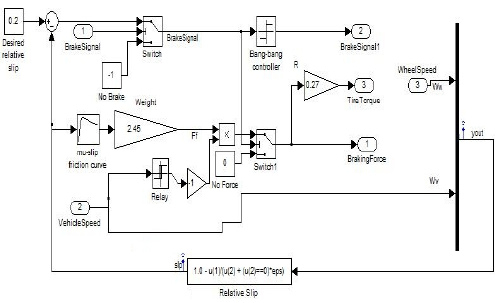
**3. Benefits of ABS :**

* Prevents skidding
* Improves steering control while braking
* Reduces chances of accidents
* Works automatically in real-time

**4. Conclusion**

ABS is a crucial technology for modern vehicles. It adapts braking to the road surface, keeping drivers safer under different conditions. While ABS does not reduce stopping distance in every case, it gives drivers more control, which is essential for avoiding accidents.

* **Architecture diagram :**

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* **Code Explanation Video :**

[**https://drive.google.com/file/d/1D7LvThqb3A\_np295STCHsgXYojqc\_3tE/view?usp=drive\_link**](https://drive.google.com/file/d/1D7LvThqb3A_np295STCHsgXYojqc_3tE/view?usp=drive_link)

* **GitHub Link :**