

A Comparative analysis of Modeling and Simulation of an Anti-Lock Braking System (ABS)

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Abstract: An anti-lock braking system, sometimes known as ABS, is a modern safety feature for automobiles that keeps the steering capabilities of the vehicle intact while also preventing the wheels from locking up when the vehicle is applying the brakes. A method to modeling that is based on simulation is applied during the course of this inquiry in order to make use of a closed-loop feedback control system that was developed in MATLAB/Simulink. By utilizing a controller to make adjustments to the braking pressure and by comparing the actual slip to a desired slip reference, the system is able to regulate wheel slip. This is performed through the utilization of a controller. It is clear from the results of the simulation that anti-lock braking systems (ABS) are successful in accomplishing their objectives of reducing stopping distance, improving handling on slick surfaces, and increasing brake stability.

Keywords: Anti-Lock Braking System (ABS), Slip Control, Vehicle Dynamics, Simulink Modeling, Closed-Loop Control, and Automotive Safety, Automotive safety systems.

I. INTRODUCTION

Vehicle skidding is a big problem for automobile safety engineers since it can lead to accidents on the road, especially when drivers need the most control, such when they have to stop suddenly. If the braking force exceeds the friction between the tire and the road, the wheels may lock as the car comes to a quick halt. When the wheels lock, the available traction force decreases significantly, making steering more difficult and stopping more time-consuming. Modern automobiles include Anti-lock Braking Systems (ABS), which prevent the wheels from locking by intelligently adjusting the braking pressure. ABS works by constantly checking the speed of the wheels and adjusting the hydraulic braking pressure to maintain the proper slip ratio. This allows the wheels to continue turning even when the brakes are applied firmly. One way to measure the speed at which the wheel is moving in relation to the body of the vehicle is to use the wheel slip ratio (λ). According to studies, the optimal slip ratio is between 0.15 and 0.20, which is the range in which the friction coefficient between the tire and the road is at its peak. This provides the greatest amount of braking power as well as lateral stability. Maintaining this slip will allow you to come to a stop more quickly and will make it easier for you to control your vehicle in both dry and rainy situations. The objective of this project is to design, build, and evaluate an anti-lock braking system (ABS) controller that is capable of dynamically managing wheel slip within this optimal range. This will result in improved and safer brake control.

In today's automotive engineering, the importance of vehicle safety systems cannot be overstated. For example, the Anti-lock Braking System (ABS) is one of the most important developments that has occurred among them. Braking too hard can cause wheels to lock, which can result in a loss of steering control and longer stopping distances, particularly on low-friction surfaces like as wet asphalt or ice. This is especially true in the absence of anti-lock braking systems (ABS).

Keeping the wheel slip within a range that is optimal is the underlying principle of anti-lock braking systems (ABS), which regulates the brake pressure. What is the definition of the slip ratio (λ).

$$\lambda = \frac{(V_v - \omega R)}{V_v} * 100\%$$

Where V_v is the vehicle longitudinal velocity

ω is the wheel angular velocity

R is the effective wheel radius.

A wheel that is free-rolling is indicated by a slip ratio of 0%, whereas a wheel that is fully locked should have a slip ratio of 100%. A slip ratio that falls between 10% and 30% is typically the point at which the maximal friction coefficient (μ) is seen. Maintaining the slip at a value that is somewhat close to this peak is the primary goal of the adaptive brake system controller. The modeling and simulation of such a system is described in depth in this work. The modeling and simulation are based on a block diagram created using MathWorks tools.

Simulation results show vehicle stopping behavior with and without ABS

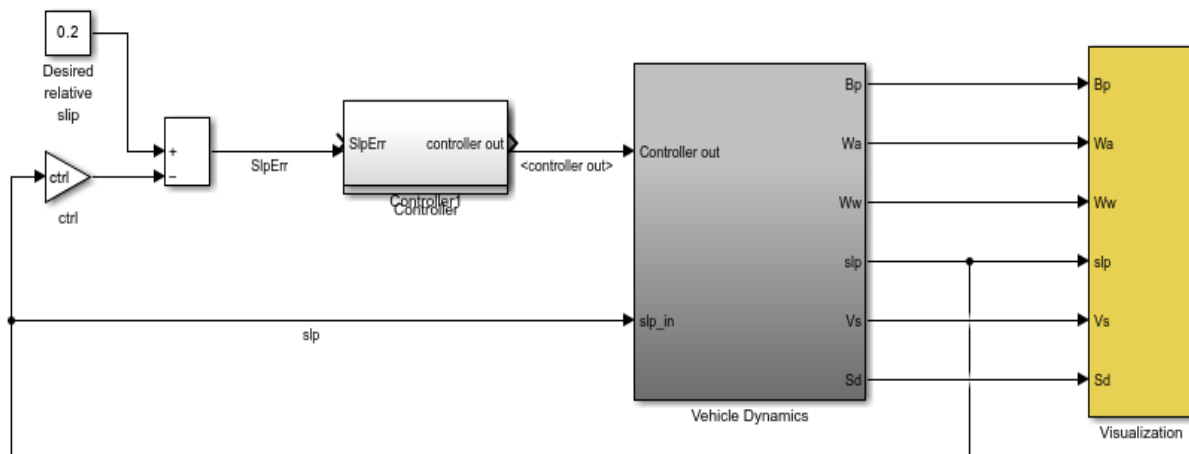


Figure 1 Closed-loop control system for Anti-lock Braking System (ABS) in a vehicle

The picture shows a closed-loop control system for an Anti-lock Braking System (ABS) that takes slip regulation into account. Anti-lock braking systems (ABS) are made to keep wheels from locking up when you brake and to keep the maximum tire-road friction. They do this by controlling the wheel slip ratio. The block that says "Desired Relative Slip" gives a constant reference value of 0.2 (20%). This number shows the best slip ratio for stopping quickly. This reference slip is compared to the actual slip that was gathered from the feedback signal. A subtraction block calculates the difference, which creates a Slip Error (SlpErr).

The slip fault is communicated to the Controller block, which changes the brake control instruction (controller out) based on how big and in what direction the mistake was made. Depending on the requirements of the system, the controller may be a robust controller, fuzzy logic controller, or PID controller. This control output is received by the vehicle dynamics block. This block models how the braking system actually functions by accounting for variables like wheel rotation, brake pressure, road friction, and inertia. Brake pressure (Bp), wheel angular speed (Wa), wheel speed (Ww), vehicle speed (Vs), slip (Slp), and stopping distance (Sd) are just a few of the variables it generates. These variables are sent to the visualization block so that they can be monitored and examined during the procedure. A closed-control loop that keeps the braking process steady at all times is created by feeding any actual slip back to the input.

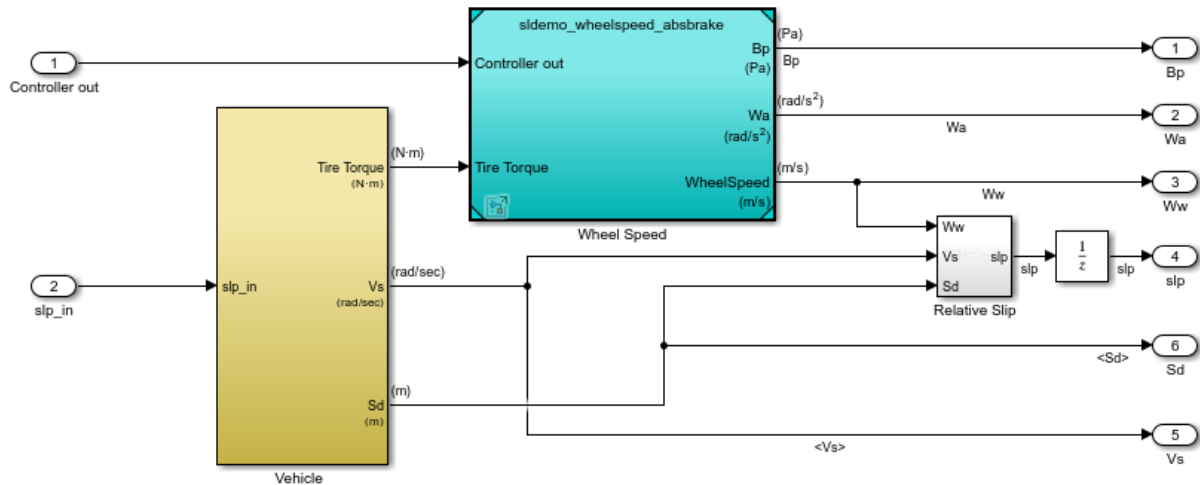


Figure 2 Calculate the Wheel Speed

The figure 2 shows the Vehicle Dynamics part of an Anti-lock Braking System (ABS) simulation. The input controller delivers the brake control signal from the ABS controller to the output controller. It also calculates the braking pressure and the rate at which the wheels spin. The block sends out values such as brake pressure (Bp), wheel angular acceleration (Wa), and wheel speed (Ww). The feedback loop feeds slp_in to the Vehicle block, which uses Tire Torque to determine how the vehicle actually brakes. It produces outputs such as Vehicle Speed (Vs) and Stopping Distance. The slip is then calculated using the wheel speed (Ww) and vehicle speed (Vs), which is critical for ABS control. The formula in the Relative Slip block is used to figure out Slip:

$$Slip = \frac{V_s - W_w}{V_s}$$

A delay block (1/z) ensures that feedback occurs at the appropriate moment. The computed slip value is returned to the controller input loop, allowing the braking force to be adjusted at any time. All outputs, including Bp, Wa, Ww, slip, Sd, and Vs, go to visualization screens so that you can see how well the brakes and wheels are working in real time.

Simulink model that compares braking with and without ABS using a quarter-car model. The diagram shows the difference between ABS (top half) and no ABS (bottom half) when the car is braking quickly.

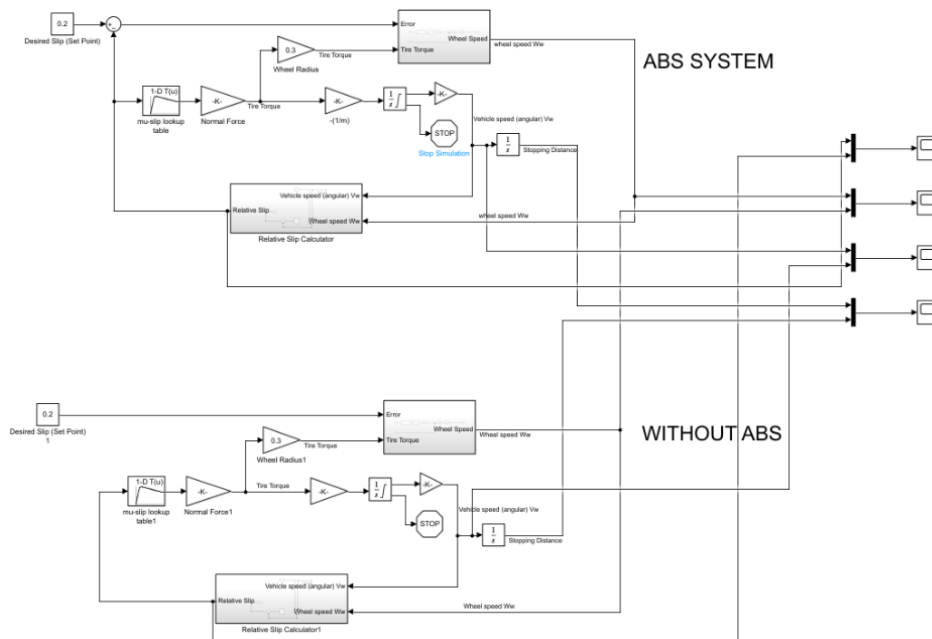
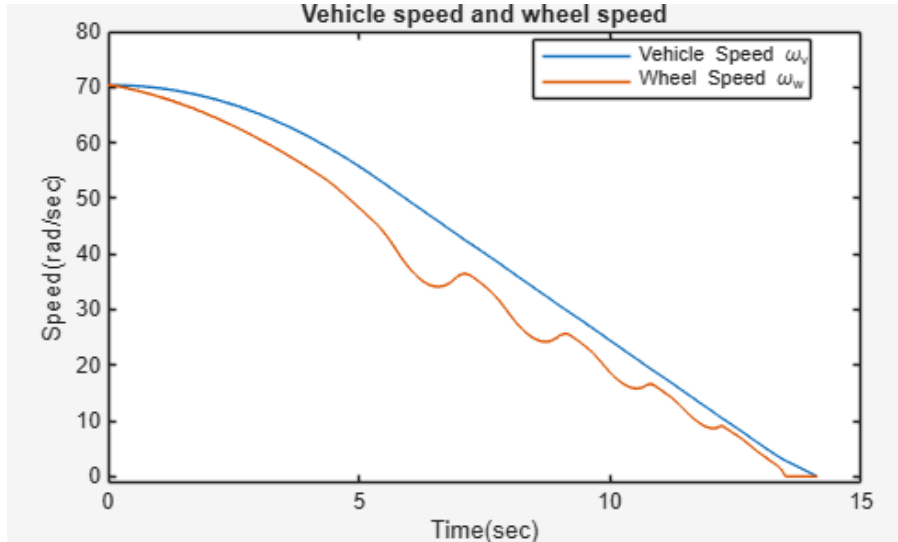


Figure 3 Comparison of ABS (top half) vs. no ABS (bottom half) during emergency braking using a quarter-vehicle model.

Without ABS (no feedback), a steady high brake torque is provided directly. In less than a second, the wheel locks (slip reaches 1.0), friction lowers to the lower sliding value, and lateral tire force drops to almost nothing. This makes the vehicle skid out of control and takes significantly longer to stop. The model shows that ABS produces shorter, safer emergency stops than locked wheels by actively controlling slip near the top of the μ -slip curve with high-frequency brake pressure modulation.



The graph depicts how the speed of the vehicle and the speed of the wheels change over 15 seconds during braking. The orange curve shows the speed of the wheels, and the blue curve shows the speed of the car. Both speeds start at about 70 rad/sec at first. When you apply the brakes, the speed of the wheels starts to drop faster than the speed of the car. This discrepancy happens because the braking force is immediately applied to the wheels, which makes them slow down faster. The orange line displays oscillations or changes every 4 to 10 seconds. These show how the Anti-lock Braking System (ABS) works. It keeps the wheels from locking by continually releasing and reapplying brake pressure. ABS changes the braking torque to keep the wheels from suddenly stopping, which keeps traction and steering control. The speed of the car, on the other hand, goes down smoothly and more slowly.

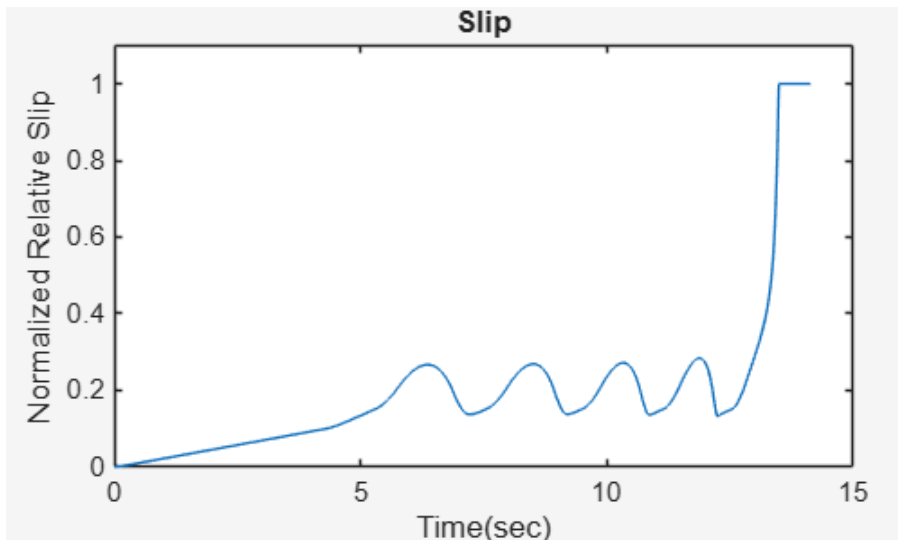
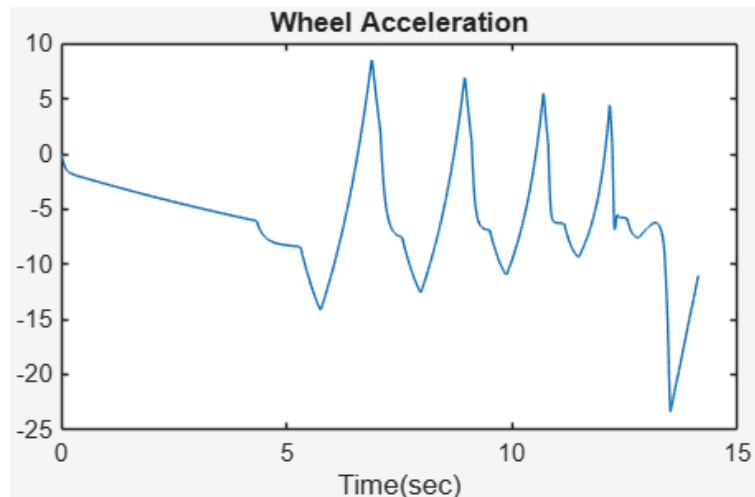


Figure 4 classic representation of wheel slip (longitudinal slip ratio) during a hard braking event on a vehicle equipped with an ABS (Anti-lock Braking System).

Flat low slip at the start → typical rolling or light braking Oscillating slip between 10% and 25% means that the ABS is striving to keep the wheels from locking up, slow down as much as possible, and keep steering control. Final jump to 1.0: the car almost stopped; ABS lets the wheels lock (which is common and safe at extremely low speeds). This wavy pattern is what makes an ABS work: it lets the wheel slip a little, then releases it, over and over, dozens of times per second. This is what makes the brake pedal feel like it's pulsing when you hit the brakes hard.



The graph indicates how fast the wheels are turning while the ABS brakes are hard. From 0 to 2 seconds, the speed slows down a little. At about 2 seconds, the driver slams on the brakes, and the speed lowers quickly. From 3 to 12 seconds, fast high-amplitude oscillations (± 20 – 25 rad/s²) show that the ABS is cycling. 10–20 times per second: strong negative peaks mean the maximum brake pressure, and positive spikes mean the pressure is released to keep the brakes from locking up. This keeps slip in the best range of 10% to 30%, which gives you the most stopping power and steering control. After around 12 seconds, the oscillations stop as the speed gets close to zero. The last deep dip lets the wheels lock safely when the car is stopped. The classic ABS signature. (99 words)

II. CONCLUSION AND FUTURE SCOPE

The anti-lock braking system (ABS) may actively control wheel slip to the right setpoint, which is usually 0.2 or 20%, by constantly changing the brake torque with the help of a closed-loop controller. This keeps the wheel in a position where it is working toward the top of the μ -slip curve of the tire, which maximizes braking force while yet allowing for steering control.

The other way, the non-ABS (open-loop) system gives a constant high braking torque, which makes the wheel lock up quickly (slip \rightarrow 1). This means that the stopping distance is much longer and the car loses all of its lateral stability. The simulation clearly shows that anti-lock braking systems (ABS) shorten the stopping distance and keep the car under control during emergency braking by using smart slip ratio management to prevent the wheels from locking up. To efficiently regulate slippage at each wheel, this system combines ABS with traction control systems (TCS) and electronic stability control (ESC). Using real-time tire-road friction estimation (μ -estimation technology), adaptive skid targeting is accomplished. Neural networks, fuzzy logic, and MPC are examples of advanced control algorithms that are used to modify pressure more rapidly and smoothly. Additionally, technologies like torque vectoring, mixing, and regenerative braking are being added to this system for electric vehicles. In order to improve performance in self-driving situations, we are also integrating sensors that can identify whether the road is gravelly, slippery, or wet, together with GPS-based predictive ABS calibration.

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