# Mechanical Braking Stability Control Based on Automobile Anti-Lock Braking System

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***Abstract- An anti-lock braking system (ABS) keeps the wheels of a vehicle from locking up while it brakes, protecting steering control for the driver. It functions by quickly controlling the brakes, considerably more quickly and effectively than a driver might apply the brakes in an emergency. As a result, the driver can steer around obstructions while braking to avoid sliding. This article shows the results of a study comparing the braking characteristics of vehicles with and without Anti-Lock Braking Systems (ABS). The deceleration mechanism was investigated through experimental analysis. The relationship between the primary driving speed and the deceleration of vehicles with and without ABS was found. The study also focused on the braking of vehicles with and without ABS on dry and wet surfaces, such that it was found that an ABS-equipped braking system of a vehicle performs better on a wet surface compared to a dry asphalt road surface***

***Indexed Terms- Anti-Lock; Braking system; Control; Stability; Vehicle***

## I. INTRODUCTION

An automobile braking system is very useful in the transportation sector due to its ability to control the car during driving and emergency stopping conditions, especially for speed control under a traffic situation. Traffic congestion requires adequate and sustainable power to avoid casualties and in such a situation, the braking system of a car must be as reliable as possible to be able to control the vehicle dynamics appropriately. The movement of vehicles in difficult conditions relies on the braking system to bring the vehicle under control and safe situation. In addition to the traditional mechanism of braking system is the Antilock Braking System (ABS) is used due to its faster and reliable response to emergency braking in automobiles. Presently, many other efficient braking systems have been invented, such as Electromechanical Brake (EMB), Electronic Wedge Brake (EWB), Electro Pneumatic Brake (EPB) and Electro-Hydraulic Brake (EHB) [1-5]. Every car manufacturer depends on the Anti-lock Braking System's (ABS) functionality as a vital safety feature. As the part that attaches the car to the ground and produces braking force, the tyre is crucial to an ABS braking manoeuvre. The ABS of the car is impacted by the tire's steady-state and transient characteristics, which in turn affect the vehicle's performance and operational efficiency.

It was reported by Han et al. [6] that ABS braking systems have been the most reliable and efficient braking system among others in the context of their greater braking torque, easy control, fastest response, nominal system complexity, and low power consumption compared to others in the same category. The application of the ABS braking system is commonly known in the automobile industry, but there is a known fact that different vehicles exhibit different efficiency concerning their braking capabilities. On this account, many considerations need to be investigated, especially for the operational efficiencies of different ABS vehicular systems. In the application of an automobile braking system, the aspect of safety is a critical phenomenon and must be understood to prevent failure during operations. Wheel lock-up during braking is avoided by antilock braking systems, which are closed-loop control devices that preserve steering and vehicle stability. When wheel lock-up occurs as a result of excessive braking force, ABS detects it and limits the braking pressure to stop it. When there is a significant rise in wheel deceleration, the ECU detects wheel lockup. In a closed-loop procedure, braking force is reapplied until wheel lockup is detected once more, at which time it begins to decrease. In order to keep steering control and keep the brakes operating close to their most efficient point, braking power is applied and reduced cyclically.

The practical outcome is that on dry bitumen, a vehicle's stopping distance with locked wheels is comparable to that when ABS is engaged, but it is significantly greater on wet surfaces. The ability for the driver to steer during emergency braking is the most well-known benefit of ABS. When the wheels of a car with a traditional braking system tend to lock up, the lateral friction that allows steering decreases significantly and, when fully locked, approaches zero. In order to retain steering control in vehicles equipped with ABS during emergency braking, lateral friction between the tyre and the road surface is kept at a high level by preventing wheel lock-up. Therefore, this study intends to test the experimental capability of the ABS braking system using four different real vehicles.

Statement of problem

ABS brake controllers can present different challenges, such as a problematic unstable equilibrium situation for optimal performance, an unsuitable measurement signal affecting controller performance, among other faulty conditions. For ABS systems, numerous control strategies have been devised. The theoretical foundations of these approaches vary, as does their effectiveness in varying road conditions. The paper aims to ascertain the efficacy of the braking system synthesis process by conducting real-world trials on the ABS braking system performance of different cars.

## II. LITERATURE REVIEW

The braking control circuits and a friction control system in each wheel make up an antilock braking system. Both disc and drum braking systems are available for use in automobiles. Compressed air and hydrostatic fluid linkage enable the appropriate operation of vehicle braking pedal systems. The various static loads, as well as the dynamic surge and reduction of the wheel loads throughout the braking process, must be appropriate while distributing the brake force among the wheels. To prevent the vehicle from becoming unstable, it is important to make sure that the locking mechanism is operated correctly during the braking process. This means that the rear wheels should never lock first. The structural mechanism of an automobile's braking control system is presented in Fig. 1. The ABS is the electronic controller in the braking system that keeps the vehicle from locking up when the braking is applied while the vehicle is moving. The ABS measures and controls the wheel speeds electronically through an automated process. The ABS proportionally lower the brake pressure for the wheel that is likely to surpass a particular amount of slip. In Fig. 2, the basic components of the ABS are shown. An automobile with an ABS braking system can maintain faster control during braking, which lowers the risk of collisions for inexperienced drivers. The foundation of safety in contemporary automotive systems relies on the use of ABS.

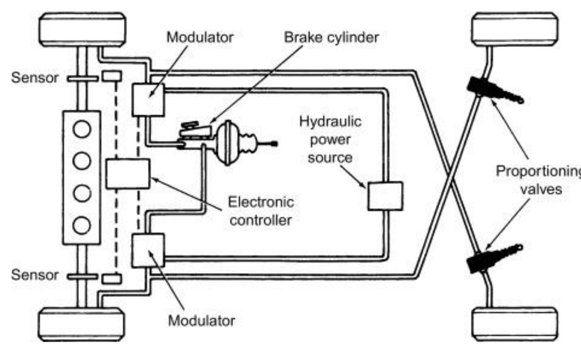


Fig. 1: Structure of automobile braking control system [7]

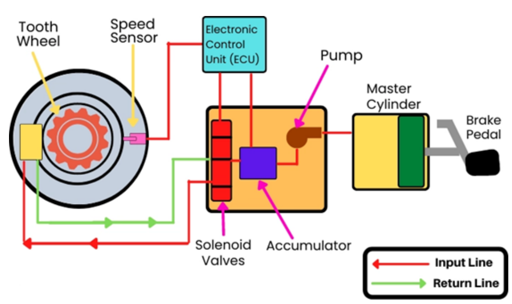


Fig. 2: Components of the ABS

To maintain steering control, particularly in situations where one or more of the vehicle's wheels lock, an antilock brake system is required. When braking, there is a chance that a car will slip off the road, prolonging the stopping distance and causing tyre wear. To prevent locking, the ABS acts as a control system that modifies the brake pressure [8]. To make sure that locking does not occur under any circumstances, continuous wheel monitoring and pressure adjustments are necessary. ABS is principally valuable in emergency braking situations and helps drivers maintain control even in slippery circumstances, allowing vehicles to stop faster without losing steerability and preventing wheel lock-up [8]. ABS is an active protection feature in vehicles with the capability to increase the brake force between the tyre and the road in the event of an emergency condition. The Optimization of Commercial Vehicle Mechatronics Composite ABS Braking Control Considering Braking Efficiency and Energy Regeneration was studied by Wang et al. [9]. The outcome showed that the mechatronics composite brake system is efficiently coordinated by the control method.

It is commonly understood that emergency braking is the only way to prevent cars from road accidents. However, in the course of an emergency braking, the wheel abruptly locks, considering that the braking moment is greater than the friction moment between the tire and the road, based on the strong brake pedal force. When the road is wet, there is a likelihood that the situation will get worse more quickly. The ABS installed in a car provides a mitigation against this problem, and subsequently provides safe braking irrespective of the road condition and prevents the wheel from locking up. An ABS uses the slip ratio as a control variable to respond to any braking emergency by modulating the brake pressure appropriately [10]. In Wang and Zheng [11], four categories of the analysis of the ABS compound braking system's control strategy were studied with consideration for motor constant hydraulic coordination, hydraulic constant motor coordination, motor maximum hydraulic coordination, and motor hydraulic mutual coordination. System reaction speed, stability, energy recovery rate, and implementation complexity are used to compare the benefits and drawbacks of various control strategies.
In the use of ABS, low braking initial speed prolongs the application time of brake pressure and the system response time, causing brake pressure to build up and decrease over a longer period. Weak speed indications from low speed also make it exceedingly difficult to decide how to adjust the wheel's speed and acceleration. Therefore, the wheels' braking torque is less than what is required. Due to these abrupt variations in wheel speed, the influences of a frail wheel speed signal are mostly visible in critical traffic circumstances. To understand how low and high speeds affect ABS braking effectiveness in various vehicle systems based on various technologies, this study examined the effects of both wet and slippery road conditions. The test results demonstrate that regardless of road conditions, low speed impairs ABS braking performance, control, and stability.

Method and Experimental Procedures
This study involves the utilization of experimental procedures that utilize five different types of cars, namely the Toyota Corolla, Ford Focus, Honda Accord and Audi A4 equipped with ABS braking systems as shown in Fig. 4. A deceleration system was connected to measure the decrease in speed of the vehicles during the experimental investigations. A suitable and safe asphalt-smooth road was used for the experimental investigation, such that the tires of the vehicles are not prone to bumpy road disturbances. The braking application experiments were conducted in two different conditions on dry and wet road surfaces. The cars were equipped with new tires. The air pressure gauge of the tires was taken into consideration for normal air inflation, and the wheel balancing of the cars was also ensured to be in proper condition. The cars were loaded with four passengers with a total weight of 185 kg. The experimental test speeds adopted ranged from 20 to 100 km/hr on a non-rough wet and dry road. For the experiment conducted on a wet road surface, the selected speed varied between 20 to 50 km/hr, while on a dry road, the speed was varied between 20 to 100 km/hr due to the quest for safety. The measurements were taken with the help of a *decelerometer*, with a connector to a pedal force, and subsequently analysed. The meter is an effective diagnostic and compliance equipment made to test the automobile emergency and service brakes.

Fig. 4: Vehicles used for the field experimental work

Operational Control of Vehicle Braking System

For an automobile's braking system to generate the maximum amount of braking power possible on any surface, each brake's output must be precisely proportionate to the weight of the wheel [12]. Theoretically, both wheels on a single axle carry the same weight, such that the brake output accounts for equilibrium axle loading [13]. The load on a vehicle's different axles at the precise instant when the brakes are applied fluctuates depending on the weight transfer that takes place during braking. The effectiveness of the vehicle's braking system dictates the passengers' safety. Therefore, while designing a new car, special attention is paid to the development of the braking system. One of its primary stages is simulating how the automated control system and the synthesised braking system operational mechanism [14]. A trial model experiment to verify the theoretical results during simulation is absolutely necessary. As a result, the simulation model must be sufficiently accurate. To simulate the car's braking system, a single simulation model must incorporate electric control circuits with an automatic control system based on a microcontroller, the hydraulic system's operation based on the braking fluid's properties, and the linear and rotational motion of mechanical parts [15]. As illustrated in Fig. 5, the longitudinal force generated at each tire is known to be influenced by the longitudinal slip ratio, the tire-road friction coefficient, and the applied normal force.

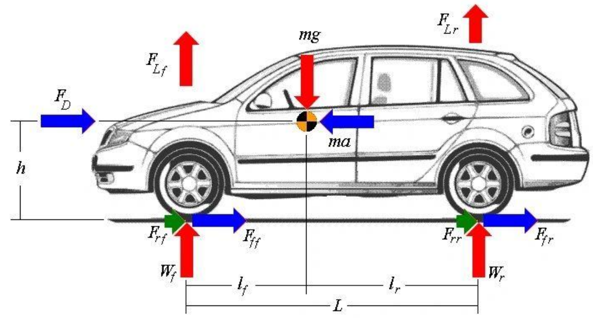

Fig. 5: Deceleration forces acting on a vehicle during a braking process [16]

Comparison of a Vehicle with and without ABS

There are significant differences in the braking system between the two cars, one with ABS and the other without ABS. In cars without ABS, the braking acceleration decreases as the driving speed increases, but in cars with ABS, it increases when the driving speed is above 100 km/h, and then decreases as the speed increases [16]. A normal interaction occurs between the wheels and the road surface in braking vehicles equipped with ABS. The phase of increased deceleration is followed. As a result, the beginning of braking typically has lower deceleration values, while the steady phase of braking and its end typically have the highest values. This situation is captured in Fig. 6, showing that a car with ABS will decelerate more when its starting speed increases. On the other hand, it has been established by Sokolovskij [17] that a car in good technical condition without ABS will decelerate to its maximum in the braking scenario at the start of the braking process, after which it will continue to decrease. The situation is such that the vehicle's wheels are locked before the deceleration reaches its peak. As shown in Fig. 7, breaking a locked wheel is less effective; thus, after they lock, there is a slight decrease in braking acceleration. Since the braking force may be restricted by the brakes' structure and the technical conditions, it is impossible to verify a vehicle's braking efficiency without an experimental investigation if its wheels are not locked. Conducting an experimental study can improve the accuracy of determining a vehicle's deceleration conditions.

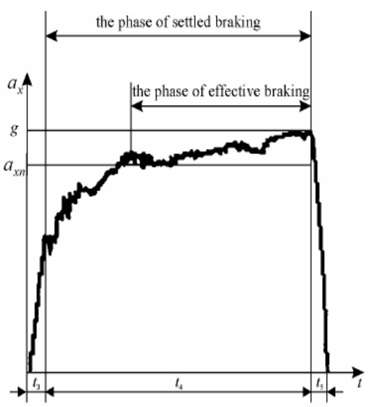


Fig. 6: The braking diagrams for a vehicle with ABS [16]

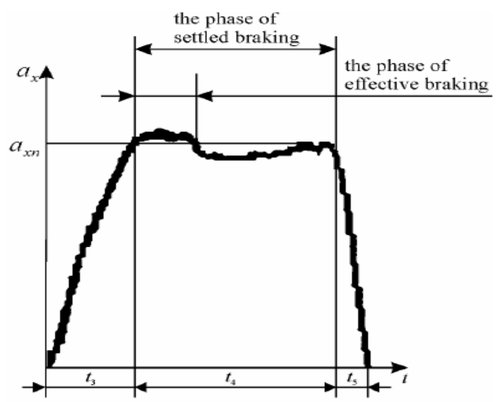


Fig. 7: The braking diagrams for a vehicle without ABS [16]

Results of the Experimental Work

The brake decelerometer can be used to detect deceleration, which is the direct result of braking force or a decrease in speed at a particular rate. Once the brake is applied long enough for the device for a car to slow down, its speed can be measured with the aid of a deceleration meter. Such a device is perfect for all-time brake testing to ensure that the required minimum efficiency is being met. Managing the speed of a vehicle on hills and stopping the car when required wholly are all accomplished with the help of the brakes. One of the many factors influencing how well a set of brakes serves its duty is the condition of the road surface, which is entirely outside the driver's control. The design and quality of the brakes are distinct from other factors, such as tyre condition and gross vehicle weight, even though the driver is ultimately responsible for them. Thus, braking efficiency refers to the ability of the brake to perform its function effectively. Regarding the experiments conducted, it was found that ABS would not significantly reduce stopping distances when the road surface is dry. Nonetheless, ABS is quite good at cutting down on stopping distances on wet road surfaces.

The pattern of the deceleration based on the primary speed of the vehicles without ABS used for the experiments is shown in Fig. 8. It can be seen that with the increase in the primary speed of the vehicles, the deceleration of the vehicles decreases as well. While conducting the testing of the settled deceleration through experimental work for the vehicle without ABS in the braking system, the average settled deceleration was within the limit of 5.7m/s$^2$ and 9.15.7m/s$^2$. The making deceleration values obtained from all the four vehicles used for the experiments which were 9.1m/s$^2$, 8.4m/s$^2$, 8.6m/s$^2$and 9.0m/s$^2$ respectively for Toyota Camry (TC), Ford Focus (FC), Audi A4 (AA) and Honda Accord (HA) are not above the standard deceleration of a free fall object of 9.8m/s$^2$. Regarding the diagram provided in Fig. 7, a car in good condition without ABS reaches its maximum deceleration from the very beginning of braking until the wheels are still unblocked. A significant amount of deceleration is lost as the wheels become blocked because it is less effective to hold up the blocked wheel. As a result, when driving a car without ABS, the peak of deceleration plays a larger role in the entire braking process when the vehicle is moving at a slower speed, and the peak plays a smaller role when the vehicle is moving at a faster speed, and the braking process takes longer.

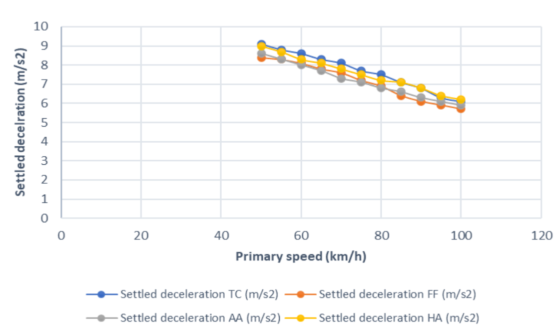


Fig. 9: Deceleration on the primary speed holding up the vehicle equipped without ABS

Contrarily, as shown in Fig. 9, the results are presented for the investigation executed for vehicles equipped with ABS. The holding up situation of the vehicles equipped with ABS exhibits different scenarios concerning the braking mechanism of the wheels. In this situation, the increase with increase in the primary speed of the vehicles is shown in Fig. 9. The settled deceleration of the vehicles against the primary speed. It was observed that the average deceleration increased from 6.4m/s$^2$, 5.5m/s$^2$, 6.2m/s$^2$ and 6.2 m/s$^2$ to 9.5m/s$^2$, 8.2m/s$^2$, 8.8m/s$^2$ and 9.2 m/s$^2$ correspondingly for TC, FC, AA and HA. The experiment conducted with a vehicle equipped with ABS was carried out on a dry asphalt road surface. The wheels of cars with ABS were found to remain unobstructed when applying brakes. This meant that there would not be a deceleration peak at the start of the braking process, as shown in Fig. 6. However, the way the ABS installation operates keeps the wheel from sliding when the braking system is holding up, which leads to a situation where deceleration keeps increasing slightly. The deceleration values of a brake system with ABS are slightly smaller at the start of the deceleration process, while the maximum values are often obtained when the braking process stabilises at the end.

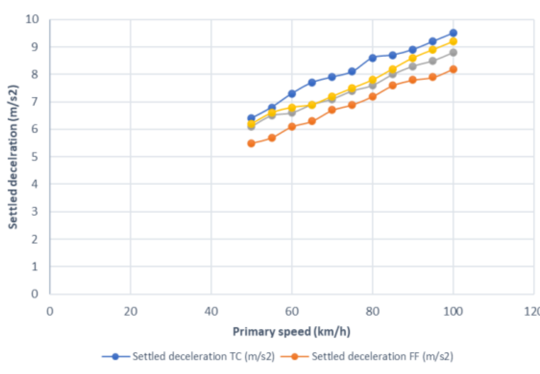


Fig. 8: Deceleration on the primary speed holding up the vehicle equipped with ABS

Furthermore, the results presented for the different vehicles unveiled some small differences concerning the settled deceleration with respect to the primary speed for the vehicles equipped with and without ABS. For example, for vehicles equipped with and without ABS, the TC exhibited the slightly highest deceleration values while the FF showed the lowest values. In this instance, the TC without ABS exhibited a somewhat greater deceleration. The reason is that the vehicle's blocked wheels without ABS make contact with a road that has a tiny film of wetness on it, which forces the vehicle to slow down. Additionally, as the wet road surface gets more flooded, it blocks the wheels. The impact is akin to holding up the vehicle on a soft surface like a sandy road surface, where deceleration could be less severe. Nonetheless, it should be emphasised that ABS stand out for having a major positive impact on the vehicle's operation as long as driving is still possible, even in situations where it is used to hold up a vehicle on a very wet surface. This is crucial for traffic safety and control mechanisms because the majority of accidents happen in situations where drivers are unable to control their vehicles.

## CONCLUSION

This study has attempted to quantify the significance of ABS in a vehicle's brake control system in terms of braking potential capacities. The most efficient braking usually surpasses 9 m/s$^2$, which is met by the TC vehicle. On the road surface, the average settled deceleration for cars with ABS when braking usually ranges from 5.5 to 9.5 m/s$^2$. Additionally, the values obtained fell between 5.7 m/s$^2$ and 9.1 m/s$^2$, whereas the average settled deceleration of the vehicles without ABS while being held up on a dry surface road used to be within the limits: 6.9 m/s$^2$ to 7.8 m/s$^2$. It was determined that the average settled deceleration rises when holding up vehicles with ABS while the primary speed of the vehicle increases, but it falls when holding up vehicles without ABS. This noticeable contrast, which was characteristic of cars with ABS and those without, demonstrated the control's steadiness and the safety of a moving car that had to stop on the road. From the perspective of the experimental inquiry, cars with ABS often perform better in terms of braking circumstances on wet roads, whereas cars with ABS perform better on dry roads made of asphalt. In any event, ABS significantly improves the vehicle's control since it increases the likelihood that the vehicle will be driven safely.

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