

Intelligent Vehicle Safety Technology: Anti-lock Braking System (ABS) and its Advancements

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Abstract - Antilock Braking System (ABS) is an advanced safety feature used in automobiles to prevent locking of wheels, skidding and uncontrolled stoppage after applying hard brake in an emergency. In normal brakes, wheels lockup while panic braking causes skidding which in turn cause a loss of traction and vehicle control. This reduces the steering ability to change direction and increases stoppage distance. So the car slides out of control. While ABS is an automated system that runs on the principles of threshold braking and cadence braking to maintain optimum slip ration. ABS controller with the help of wheel speed sensors constantly monitors the rotational speed of each wheel; when the wheels are about to lock up during braking, the sensors sense that the wheel has just begun rotating significantly slower than others on the vehicle. So it actuates the valve to momentarily reduce the braking force on the affected wheel to prevent sliding of the wheels. When the wheel resumes rolling, the full braking force is again applied. ABS repeats the process until there is no longer any need for modulated braking. Some anti-lock systems can apply or release braking pressure 15 times per second. Because of this, the wheels of a car equipped with ABS are practically impossible to lock even during panic braking in severe conditions which make vehicle steering easy for drivers. So, ABS generally offer advanced vehicle control and minimize the stopping distance in a slippery and dry surface by keeping wheel slip rate in an optimal range, conversely on loose surface like gravel or snow-covered road, ABS can significantly raise braking distance, although still improves vehicle control. In this paper, will review the ABS technology and its advancements like Traction Control System (TCS), Dynamic Stability Control (DSC), Roll Stability Control (RSC) and Electronic Brake-Force Distribution (EBD) with the advanced mechatronic systems.

Key Words: ABS, Antilock Brakes, Antilock Braking System, Vehicle Safety, Advance Braking System, Advanced safety vehicle, etc.

1. INTRODUCTION

ABS is recognized as an influential innovation to road safety as it is designed to keep a vehicle steerable and stable during sudden braking moments by preventing wheel lockup. It is well known that wheels will slip and lockup during harsh braking or when braking on a slippery (wet, icy, etc.) road surface. This usually causes a long stopping distance and sometimes the vehicle will lose steerability and stability. [1-3]. The objective of ABS is to maintain the optimum wheel slip so that maximum friction is achieved and the steering

stability is sustained. That is, to make the vehicle stop in the shortest distance possible while maintaining the directional control. To get the optimum slip, ABS with the help of wheel speed sensors constantly monitors the slip of each wheel and modulates the brake line pressure of each wheel independent of the brake pedal force to achieve optimal braking performance while having steering stability. So, during the emergency braking, the wheel does not get locked even if you push a full auto brake pedal and hence the skidding does not take place. It helps a driver to control the car easier, even on roads with low adhesion, such as wet, icy and muddy road. The technology of ABS is also applied in the Traction Control System (TCS), Dynamic Stability Control (DSC), Roll Stability Control (RSC) and Electronic Brake-Force Distribution (EBD).

2. ABS COMPONENTS

2.1 Wheel-Speed Sensors

Each of the wheel speed sensors detects the speed of the corresponding wheel. The sensor consists of a permanent magnet, coil and tone wheel. The magnetic flux produced by the permanent magnet changes as each tooth of the tone wheel (which rotates together with the wheel) passes in front of the magnet's pole piece. The changing magnetic flux induces voltages at a frequency corresponding to the wheel rotational speed.

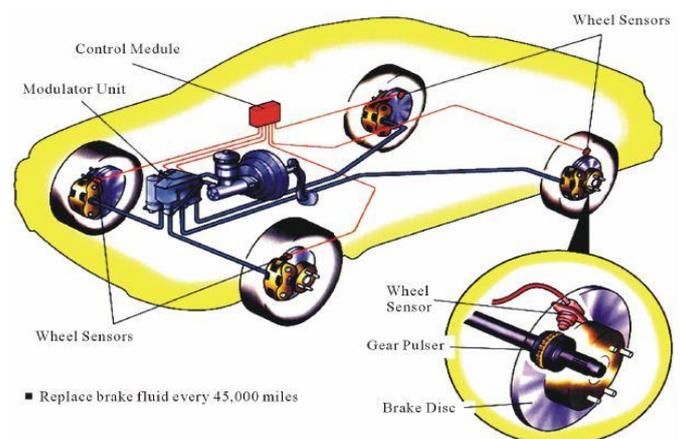


Fig -1: Typical ABS components [4]

2.2 Electronic Control Unit (ECU)

The electronic control unit receives, amplifies and filters the signal from sensors for calculating the wheel rotational speed and acceleration. The slip of each wheel is obtained by comparing the reference speed with the individual wheel. During wheel slip or wheel acceleration condition the microcomputer triggers the pressure control valve of the pressure modulator to modulate the brake pressure in the individual wheel brake cylinders.

2.3 Hydraulic Pressure Modulator/ Hydraulic Control Unit

The hydraulic pressure modulator is an electro-hydraulic device for reducing, holding, and restoring the pressure of the wheel brakes by manipulating the solenoid valves in the hydraulic brake system. Hydraulic unit actuates the brakes by increasing the hydraulic pressure or bypassing the pedal force to reduce the braking power.

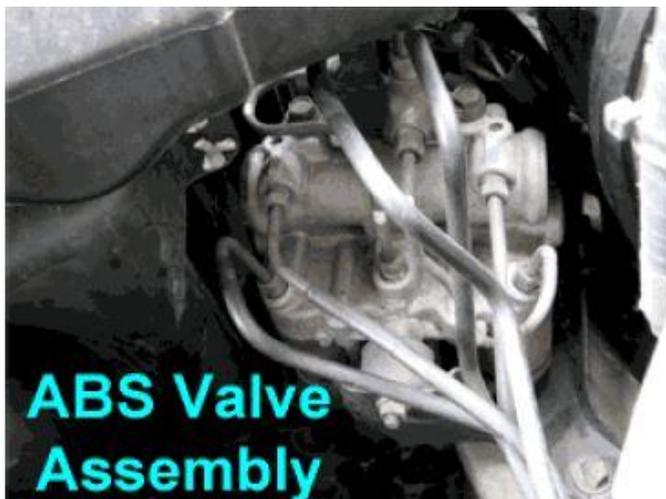


Fig -2: Hydraulic Control Unit

3. PRINCIPLES OF ANTILOCK-BRAKE SYSTEM

During sudden braking, brakes of a vehicle not equipped with ABS will instantly lock the wheels and it slides rather than rolls to a stop. The obvious consequence of skidding and lack of control caused by the locking of wheels is that an accident is far more likely to occur.

The release and reapply of the brake pedal will avoid the locking of the wheels which in turn avoid the skidding. This is exactly what an antilock braking system does. During harsh braking, ABS modulates the brake pressure as often as 15 times per seconds. [5] By modulating pressure to the brakes the friction between the tires and the road is maintained and the vehicle is able to come to the controllable stop.

Steering is another important consideration. As long as a wheel is rolling it goes only in the direction in which it is

turned. But once it starts skidding it has no directional stability. The Maneuverability of the vehicle is lost if the front wheels are locked and the stability of the vehicle is reduced if the rear wheels are locked.

ABS control module computes the slip rate of the wheels based on the vehicle speed and speed of the individual wheels, and then it modulates the brake fluid pressure to achieve the targeted slip rate that is necessary for optimal braking performance and to ensure maximum grip force from the tire to ensure Maneuverability and stability of the vehicle.

The wheel slip, S is defined as:

$$S = \frac{V - \omega R}{V}$$

where ω , R, and V denotes the wheel angular velocity, wheel rolling radius, and vehicle forward velocity, respectively. In normal driving conditions, $V = \omega R$, therefore $S = 0$. In severe braking, it is common to have $\omega = 0$ while $S = 1$, which is called wheel lockup. Wheel lockup is undesirable since it increases the stopping distance and causes the loss of steerability.

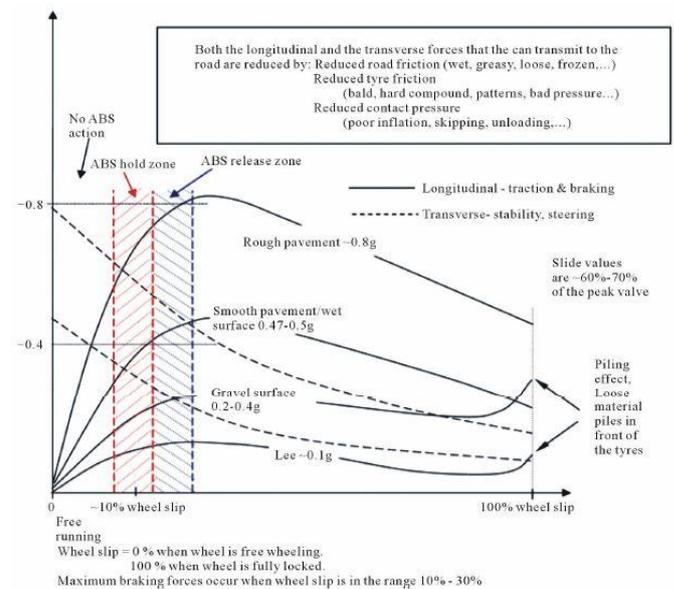


Fig -3: Illustration of the relationship between braking coefficient and wheel slip [6]

Fig-3 shows the relationship between braking co-efficient and wheel slip and also the behavior of static forces that a tire can produce during braking. The maximum retardation force occur when the wheel slip is about 10% and then falls gradually as the slip rate increases. The sideways forces (which are stabilizing and maneuvering forces) falls off consistently as the wheel slips. The maximum retardation and sideways forces that a tire-road interface can supply also falls off with surface smoothness, water/snow/loose material on the road as the weight on the tire is reduced. A locked-up

wheel provides low road-handling force and minimal steering force. Consequently, the main benefit of ABS operation is to maintain steerability of the vehicle during heavy braking. In rare circumstances, the stopping distance may be increased however; the directional control of the vehicle is substantially greater than if the wheels are locked up.

4. TYPES OF ANTILOCK BRAKE SYSTEMS

ABS is classified based on the types of brakes used. Brakes can also be differentiated by the number of channels, i.e. how many valves are individually controlled and the number of speed sensors.

4.1 Four Channel, Four Sensor ABS

This is the best combination for an effective ABS system. There is a speed sensor on all four wheels and a separate valve for all four wheels. With this setup, the controller monitors each wheel individually to ensure that it is achieving maximum braking force.

4.2 Three Channel, Four Sensor ABS

There is a speed sensor on all four wheels and a separate valve for each of the front wheels, but only one valve for both of the rear wheels. Older vehicles with four-wheel ABS usually use this type.

4.3 Three Channel, Three Sensor ABS

This combination, which is commonly found on pickup trucks with four-wheel ABS, has a speed sensor and a valve for each of the front wheels, along with one valve and one sensor for both rear wheels. The speed sensor for the rear wheels is located in the rear axle.

As the rear wheels are controlled together, they are both have to start to lock up before the ABS will active on the rear.

4.4 Two Channel, Four Sensor ABS

This system, commonly found on passenger cars from the late '80s through the mid-1990s, uses a speed sensor at each wheel, with one control valve each for the front and rear wheels as a pair. If the speed sensor detects lock up at any individual wheel, the control module triggers the valve for both wheels on that end of the car.

4.5 One Channel, One Sensor ABS

This system is commonly found on pickup trucks, SUVs, and vans with rear-wheel ABS. It has one valve, which controls both rear wheels, and one speed sensor, located in the rear axle. This system operates the same as the rear end of a three-channel system. The rear wheels are monitored together and they both have to start to lock up before the ABS kicks in. In this system it is also possible that one of the rear wheels will lock, reducing brake effectiveness. This system is

also easy to identify, as there are no individual speed sensors for any of the wheels.

5. ADVANTAGES OF ABS

5.1 Reduced Stopping Distance

The Stopping distance is one of the critical factors when it comes to braking. Stopping distance is the function of the mass of the vehicle, its initial velocity and the braking force. Stopping distance can be minimized by enhancing braking force while keeping all other factors constant. In all types of road surface, there always exists a peak in friction coefficient. ABS can achieve maximum frictional force by managing optimum slip rate which results in shortage stopping distance. This objective of ABS, however, is mitigated by the need for vehicle stability and steerability.

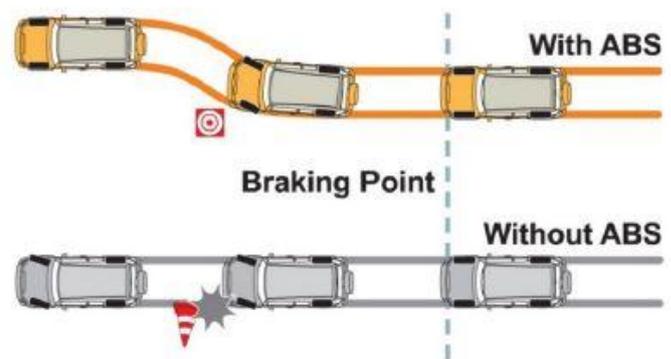


Fig -4: Advantages of ABS

5.2 Steerability

Good peak frictional force control is necessary to achieve sufficient lateral forces and, therefore, satisfactory steerability. Steerability while braking is crucial not only for insignificant course corrections but also for the possibility of steering around an obstruction. For ABS-equipped vehicles, the tire performance is of critical significance as tire features play an important role in the braking and steering response of a vehicle. All braking and steering forces must be produced within the small tire contact patch between the vehicle and the road. Tire traction forces, as well as side forces, can only be generated when a difference exists between the speed of the tire circumference and the speed of the vehicle relative to the road surface. This difference is signified as a slip. It is usual to associate the tire braking force to the tire braking slip.

After the peak value has been reached, increased tire slip causes reduction of tire-road friction coefficient. ABS has to limit the slip to values below the peak value to prevent the wheel from locking. Tires with a high peak friction point achieve maximum friction at 10 to 20% slip. The optimum slip value declines as tire-road friction drops.

5.3 Stability

Although the primary purpose of the braking system is to decelerate and stop the vehicle, maximum friction force may not be beneficial in some cases if vehicle is on a so-called p-split surface (asphalt and ice, for example), such that significantly more braking force is attainable on one side of the vehicle than on the other side. So applying a full brake on both the sides will cause yaw or skidding moment that will tend to pull the vehicle towards greater frictional surface and results in vehicle instability, and forces the driver to make excessive steering corrections to counteract the yaw moment. Here comes the concept of ABS that manage the slip of both rear wheels at the level where the lower of the two friction coefficient peaks, then a lateral force is fairly high, though not maximized. This contributes to stability.

6. EFFECTIVENESS

A 2004 Australian study by Monash University Accident Research Centre found that Antilock Braking System: [7]

- Reduced the risk of multiple vehicle crashes by 18 per cent,
- Increased risk of run-off-road crashes by 35 per cent.

7. ADVANCEMENTS IN ABS

Some systems, which work with the ABS, are Automatic Traction Control (ATC), Automatic Stability Control (ASC), Roll Stability Control (RSC) and Electronic Brake-Force Distribution (EBD) which are discussed below.

7.1 Automatic Traction Control (ATC) / Traction Control System (TCS)

Traction control is an electronic system that stops or limits the spinning of driving wheels of a vehicle in the condition of slippage to prevent loss of traction of driven wheels.

During heavy acceleration from a standstill or when one drive wheel is working on a good traction surface and the other is not, one or more wheels may lose the traction which could hamper driver control. The nature of an open differential is that the wheel with the least traction receives the most power. This is undesirable in low-traction circumstances. In such a situation, the traction control can step in. Traction Control Module monitors the data from Wheel speed sensors. If one wheel rotating faster than the others, it is a sign of traction lose, and if brakes are not applied, the control module enters into the traction control mode and reduces torque or applied braking pressure to the slipping wheels until it regains traction. Thus, TCS enables drivers to employ heavy acceleration when merging with fast-moving traffic. These systems are invented to decrease

wheel slip and maintain traction at the drive wheels when the road is wet or snow-covered.

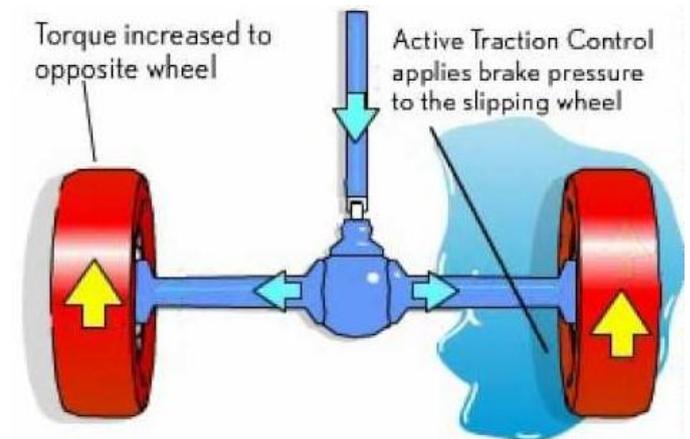


Fig -4: Traction Control System

Many systems are equipped with a dash-mounted warning light to alert the driver that the system is functioning. There also be a manual cut off switch so that the driver can turn off TCS control.

7.2 Automatic Stability Control (ASC) / Electronic Stability Program (ESP) / Dynamic Stability Control system (DSC)

The Dynamic Stability Control system (DSC) automatically takes control of the vehicle when skidding is detected. The control unit receives signals from the usual ABS sensors plus yaw, lateral acceleration (G-force) and a steering angle sensor. The system uses the angle of the steering wheel and the speed of the four wheels to determine the path chosen by the driver. It then looks at lateral G-forces and vehicle yaw to determine where the vehicle is going.

The system guards against skidding by optimally regulating engine output and the braking force applied to each wheel through the combined control of the 4-wheel antilock braking system and the Traction Control System (TCS). This supports the vehicle to maintain stability even in situations such as cornering on slippery roads or when steering abruptly to avoid hazards.

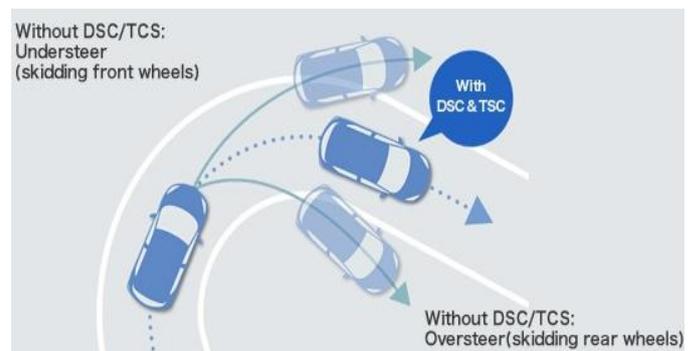


Fig -5: Dynamic Stability Control

During cornering, if front wheels lose traction it results in understeers and the system suppressed skidding by dropping engine output and applying brakes to the inner rear wheel. Conversely, if rear wheels lose traction, it causes oversteers and the system applies braking to the outer front wheel to suppress skidding.

7.3 Roll Stability Control (RSC)

This advanced safety system recognizes the possibility of a rollover through signals from the roll rate sensor and the wheel speed sensor and adjusts braking and/or torque to affect a roll moment in the opposite direction. As a result, the vehicle recovers stability rather than rolling over.

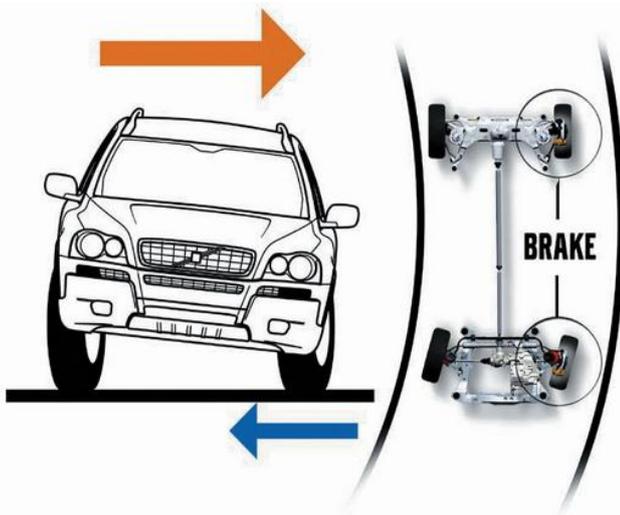


Fig -6: Roll Stability Control

During turning lateral force pushes the vehicle in the opposite direction of the turn. If this force overcomes the weight of the vehicle then rollover will occur. The vehicles having the high center of gravity (C.G.) like SUVs are more prone to rolling over. RSC sense and counteracts this lateral force. The gyroscopic sensor continually measures the degree to which the body of the vehicle is rolling and how fast that roll is occurring. Only if the roll angle and speed exceeds the safety limit and other sensor data indicates a potential rollover event, then the control module takes the action. RSC control module reduces engine power and applies break on the front wheels until they momentarily lose traction with the road by allowing the front wheels to slip straight ahead by just a few centimeters instead of moving into the turn. The turning force reduced and therefore the rollover force is also reduced. This corrects the potential rollover and still allows the vehicle to safely make the turn. RSC helps drivers to maintain control by preventing rollover during cornering or evasive maneuvers.

7.4 Electronic Brake-Force Distribution (EBD)

Electronic Brakeforce Distribution (EBD or EBFD) or electronic Brakeforce Limitation (EBL) is an

automobile brake technology that automatically alters the amount of force applied to each of a vehicle's wheels, based on road conditions, speed, loading, etc. This results in a shorter stopping distances in wet and dry conditions. When a car has EBD it reduces the brakeforce to the tire with less load to avoid slippage and locking of the wheel. EBD is only available on vehicles that have ABS.

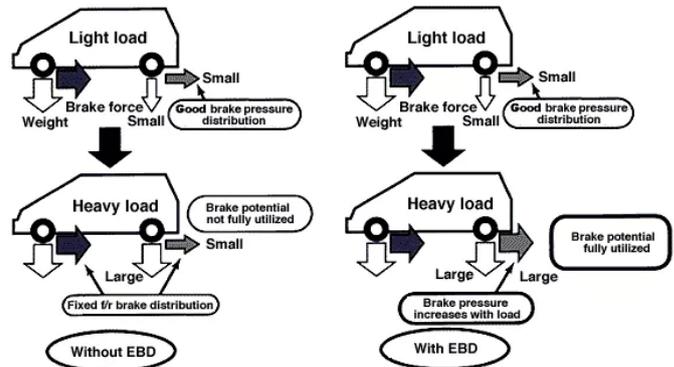


Fig -7: Electronic Brake-Force Distribution

8. CONCLUSIONS

With the automobile technology advancement, the braking system getting more and more advanced. Antilock brakes ease drivers to have better control of a vehicle during the severe braking condition by modulating hydraulic pressure in the brake line of individual wheels to make sure vehicle do not skid out of control because of locked-up wheels.

Statistics show that approximately 40 % of automobile accidents are due to skidding. These problems commonly occur on vehicles without antilock brake systems, which can be avoided by adding ABS.

Advancements in an ABS system making today's high-speed cars more and more safer.

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BIOGRAPHY



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