Parking brake: from mechanical handbrake to push-button

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Abstract

The vehicular braking system is crucial for safety and stability, having evolved significantly over the decades and playing a vital role in accident prevention. Commonly, vehicles use a lever-operated parking brake, which provides a simple solution but is limited in terms of efficiency and safety. With advancements in technology, the electronic parking brake (EPB) offers greater precision and control. Tests conducted with the stability control system (ESC) in critical driving situations demonstrate that the integration of the EPB results in improvements in vehicle safety, using data from controlled track tests. By combining the EPB with hydraulic braking systems, it is possible to optimize the vehicle's response in adverse situations. This paper demonstrates, with practical data, that the evolution of the electronic parking brake brings advantages when combined with other vehicle components, highlighting how technological innovations provide enhanced convenience and contribute to safer mobility.

Introduction

The braking system is essential for vehicle safety and control, enabling the driver to decelerate, stop, and maintain immobility. The evolution of braking systems reflects advancements in automotive technology, increasingly stringent safety regulations such as the European NCAP (New Car Assessment Programme), and market demands for enhanced efficiency. Early vehicles relied on manually-operated wooden brakes, which were limited in effectiveness [1]. The advent of hydraulic braking systems provided more uniform and responsive braking force by using brake fluid to transmit pressure from the pedal to the wheel brakes.

The parking brake, also known as the emergency brake, is a crucial component ensuring a vehicle remains stationary, especially on slopes [2]. While early systems employed manually actuated cables connected to rear brakes, modern Electronic Parking Brakes (EPBs) offer significant enhancements. EPBs replace the lever with a button for effortless engagement and can be integrated with systems like electronic stability control (ESC).

Furthermore, EPBs provide functions such as automatic release upon gear engagement and a braking backup in hydraulic failure situations, modulating braking force more precisely than their mechanical predecessors. This evolution underscores how automotive innovation elevates core functionalities, increasing vehicle safety and utility, and paving the way for advanced driver-assistance systems (ADAS) and autonomous driving technologies.

Vehicular braking system

A vehicle's braking system decelerates or stops the vehicle through a coordinated network of components. The process begins with the brake pedal, which, when depressed, actuates the master cylinder [3]. This cylinder converts the mechanical force into hydraulic pressure, which is then distributed through brake lines to the wheel cylinders or actuators at each wheel. A brake booster amplifies the force applied to the pedal, reducing driver effort.

At each wheel, the hydraulic pressure forces brake pads against rotors (in disc brake systems) or brake shoes against drums, generating friction and converting kinetic energy into heat. A proportioning valve balances braking force between the front and rear wheels to prevent premature rear-wheel lockup.

Modern braking systems often include Anti-lock Braking Systems (ABS) to prevent wheel lockup during emergency braking and electronic stability control to maintain vehicle stability during adverse conditions. The parking brake, acting primarily on the rear wheels, provides a mechanical or electronic means of immobilizing the vehicle when parked.

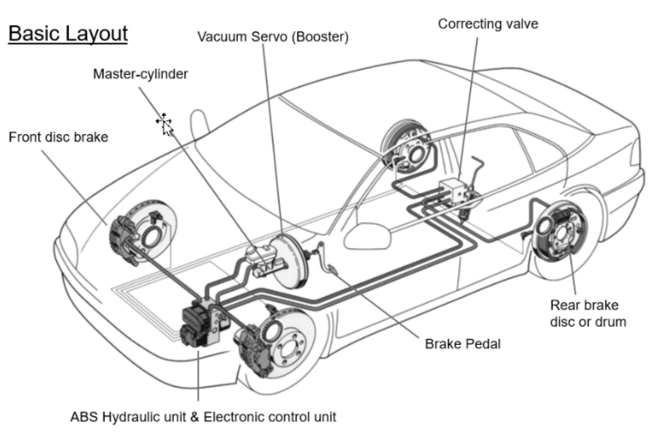


Figure 1. Braking system.

Parking Brake

The parking brake is a crucial safety system designed to prevent vehicle movement when parked, particularly on inclined surfaces. Early automotive designs employed purely mechanical parking brakes, actuated by a hand-operated lever.

This lever mechanically engaged cables connected to the rear brakes, providing a basic means of immobilization. While functional, these systems offered limited precision and required significant driver effort.

A typical mechanical parking brake system consists of several key components. A lever, typically located in the center console, is connected via an actuating cable to the rear brakes. Pulling the lever tensions the cable, engaging the rear brakes. A return spring ensures the lever returns to its disengaged position, fully releasing the brakes. These components, anchored to the vehicle chassis by mounting brackets, provided a direct mechanical link between the driver and the braking system.

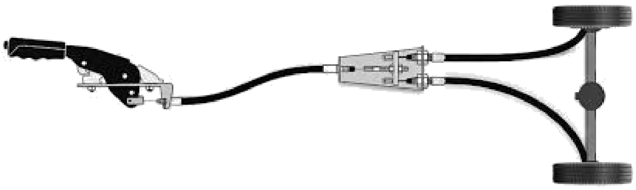


Figure 2. Mechanical handbrake system.

Although robust and relatively simple, mechanical parking brakes lacked the sophistication and integration capabilities of modern electronic systems. The effort required to engage the brake could vary significantly, and precise modulation of the braking force was challenging. The advent of electronic parking brakes (EPBs) addressed these limitations, enabling more precise control, easier operation, and seamless integration with other vehicle safety systems.

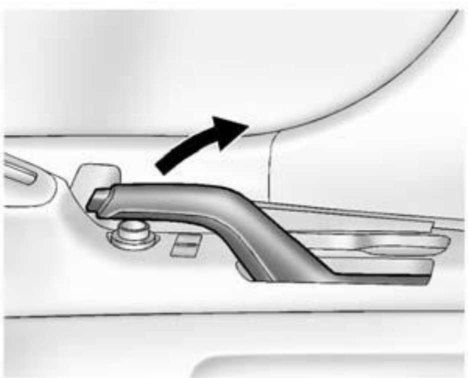


Figure 3. Mechanical parking brake lever.

Electronic Stability Control

Electronic stability control (ESC) is a critical automotive safety system designed to prevent loss of control. Introduced by Bosch as ESP® in 1995, the technology quickly became a standard feature in modern vehicles [4]. ESC monitors the vehicle's intended path versus its actual trajectory. It employs sensors, including yaw rate sensors and lateral accelerometers, to continuously assess vehicle dynamics. When ESC detects a deviation from the driver's intended course, it selectively applies braking force to individual wheels to correct steering and stabilize the vehicle.

Beyond preventing skids, ESC plays a crucial role in emergency maneuvers. By precisely adjusting braking forces, ESC helps the driver maintain control during evasive actions, mitigating accidents in critical situations.

Over time, ESC has integrated with other safety systems, such as traction control, automatic emergency braking, and lane-keeping assistance, creating a comprehensive safety net. Studies demonstrate that ESC significantly reduces the risk of fatal accidents and serious injuries. As technology advances, ESC is expected to incorporate artificial intelligence and machine learning to more effectively predict and respond to hazardous situations, solidifying its role in vehicle safety. Besides core functionalities, new comfort functions are implemented.

As vehicles continue to improve, the automotive industry also strives to provide comfort and new functions for the driver. Whether the car is automatically following another vehicle (i.e., cruise control), maintaining a fixed speed, or preventing a car from rolling down a hill while stationary, all these functionalities are related, in some way, to braking systems. The ESC does not require these functions to operate, but they enhance the customer experience and provide a safer journey for the driver. Modes of functions such as VAFs (Value-Added Functions) have been listed. In the following items, we will provide an overview of some value-added functions.

Figure 4. Electronic Stability Control module.

Electronic Parking Brake

The electronic parking brake (EPB) [5], introduced in the 1990s, revolutionized parking brake technology by replacing the traditional manual lever with a driver activation interface, enabling seamless integration with systems like electronic stability control (ESC) for enhanced precision.

A typical EPB system comprises this driver activation interface, an electronic control module (ECM), electric actuators (acting on disc or drum rear brakes), and position sensors.

The ECM monitors brake status, further enhancing safety. The EPB's primary function is to securely immobilize the vehicle under diverse conditions. Engagement occurs manually via the driver interface or automatically upon ignition-off, provided a release is not requested.

Figure 5. Rear caliper with EPB.

The electronic stability control can also initiate EPB engagement for functions like trailer stability and emergency braking. A dedicated mode is available for roller test bench analysis of performance characteristics. Redundant systems prevent button failure from fully disabling the EPB, and a request to release will override automated engagement commands. The EPB system therefore provides increased convenience and safety when initiating driving.

Manual application of the parking brake is initiated by the driver pressing the EPB button. Automatic activation occurs when the ignition or engine is turned off, provided that the vehicle is stationary and the EPB button is not being used to release the brake. External systems can request the EPB to lock for managing vehicle immobility, such as the ESC.

In automatic parking scenarios, an emergency lock request can be sent to immediately engage the brake, ensuring safety in the event of detected failures.

Additionally, in vehicles with automatic transmissions, moving the gear selector to the "P" (Park) position sends a synchronized lock request to the EPB, provided that the vehicle is stationary, and the hardware conditions are met. It is important to note that failure of the EPB application button does not prevent the overall system from functioning, acting as a redundant safety measure.

However, pressing the button in the release direction cancels any pending automatic lock request.

The EPB offers several controlled release functions for increased convenience and safety when initiating driving. These functions include manual release via button, automatic release upon detecting the intention to drive ("Drive Off Release"), release upon request from external systems, and release synchronized with gear shifting in automatic vehicles.

Safety is ensured by verifying driver presence and correct system operation. Automatic release ("Drive Off Release") only occurs if sufficient torque is available to prevent vehicle rollback, with an option for driver inhibition. Synchronized release with automatic transmission also requires confirmation of driver presence through additional signals.

When the vehicle is in motion and the driver activates the EPB button to decelerate, the system generates a controlled dynamic braking request and sends it to the ESC software.

This deceleration request is maintained as long as the EPB button is pressed and is cancelled as soon as the button is released. The driver can override the request by pressing the accelerator.

The deceleration request is sent if the following conditions are met: the EPB button is operational and pressed, and the vehicle speed is above a minimum threshold.

Figure 6. Electronic parking brake button.

Parking Brake and ESC Integration

The electronic stability control (ESC) actively integrates with the electronic parking brake (EPB) in specific scenarios to enhance vehicle safety. For example, in advanced systems, the ESC engages the EPB post-impact to ensure complete immobilization, particularly if the driver is incapacitated or surface conditions are poor. Similarly, when Trailer Stability Control (TSC) detects trailer sway, the ESC can selectively actuate the EPB to stabilize the vehicle-trailer combination [6]. This cooperative function provides more controlled and secure outcomes than either system acting independently. The Figure 7 describes how the system and the EPB are physically and logically connected – the arrangement of its components, nodes, systems and communication paths.

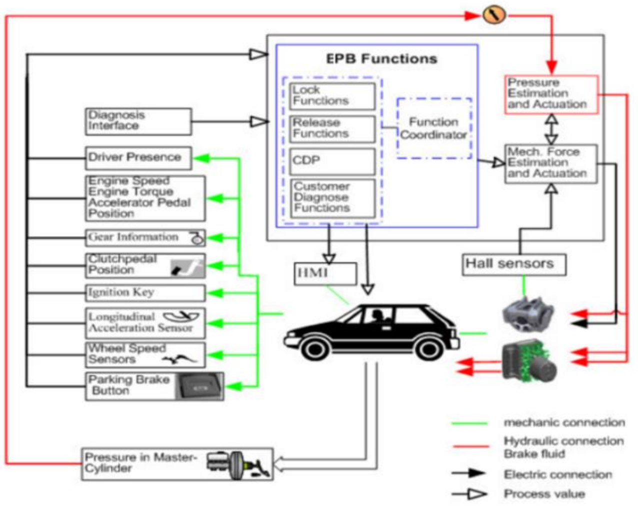


Figure 7. EPB functional topology.

Beyond its primary function of securing a parked vehicle, the parking brake system, particularly advanced electronic versions, often incorporates Value-Added Features (VAFs) enhancing safety, convenience, and overall vehicle functionality.

AUTOMATIC VEHICLE HOLD (AVH) – it is an added braking function that assists the driver by automatically maintaining a stationary vehicle without requiring constant brake pedal application [7]. Activated via a dashboard button, AVH engages when the vehicle comes to a complete stop, holding the brakes until the driver presses the accelerator. While primarily intended for temporary stops (e.g., traffic lights), AVH may not suffice on steep inclines or slippery surfaces. In such cases, the EPB will engage to provide a more secure hold.

Conversely, AVH disengages automatically when the engine is switched off or the driver's door is opened, prompting EPB activation for parking. In the event of hydraulic system failure, the EPB can serve as a backup to safely stop the vehicle.

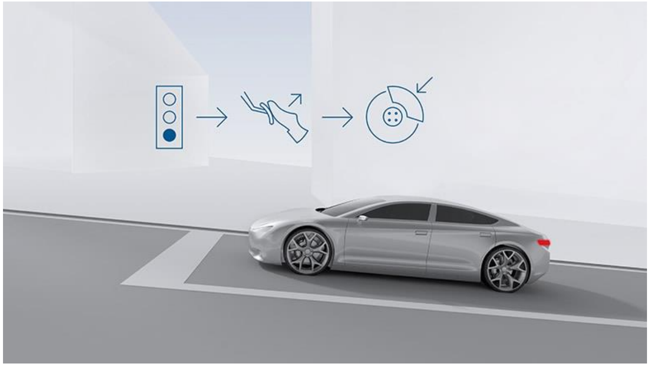
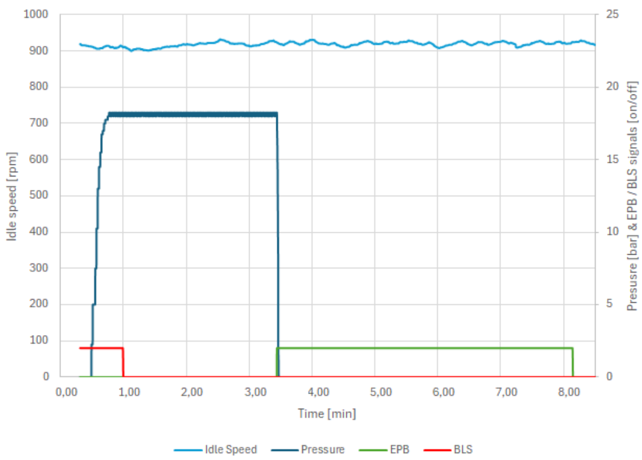


Figure 8. AVH.

The function enables controlled stops and secure vehicle holding, with the potential to engage the EPB after a set time to avoid actuator overload [8]. The system monitors actuator status to prevent overstress or accelerated wear.

With the goal of illustrating the real-world use and benefits of EPB, a team of technicians and drivers conducted a series of tests in a controlled testing environment. The following data set was obtained in order to validate the performance of the AVH feature. The below Graph 1 represents a braking event. The brake light switch (BLS) signal (red line) indicates that the brake pedal is being activated by the driver. At time around 1min, the driver releases the brake pedal. The AVH function kept on.

The hydraulic pressure in the brake system is around 18bar (blue line). At time around 3,6min, the system indicates a potential overload condition (thermal) and applied the parking brake to continue the braking process (green line). The hydraulic pressure is released. The vehicle stays immobile till the drive press the gas pedal.



Graphic 1. EPB actuation.

The EPB was not manually engaged, and the driver was unaware of any changes in the vehicle's motion. It was also possible to notice the idle speed unaffected.

The time to function active is set by OEM discussion. The scripts update may be required for the customer team during vehicle validation phase. The figure 9 shows an example of these parameters.

```
threshold_speed_mps                = 'SWP__P_ApbCtrlStandstillVehThres'
vehicle_speed_kmph                 = '60'
brake_apb_release_value            = '25'
evaluate_input_apb_signal          = %('ApbButtonState'=>"0:2") !ApbButtonState for gen 9.3 platform signal
evaluate_cdpdeactive_time          = %('CDPDeactivation.CDP_Statemachine.CDP_light_Class.CDP20ms'=>"0:1:0")
evaluate_cdp_Request       = %('CdpRequest' => "0:1:0")
evaluate_cdp_Active        =%('CdpActive' => "0:1:0")
evaluate_ecu_signals               = %('TargetStateCDP' => "2",'CdpAvailable'=> "1")
evaluate_Standstill_B_signal       = %('SSMStandstill_B' => "0:1")
evaluate_ecu_signal_v_Veh = %('v_Veh_x' => "<-16.6:>-0")
RB_mandatory_faults                = @('NoFault')
CU_mandatory_faults                = @('NoFault')
max_wait_time_Standstill_ms        = 5600
parkapplied_wait_time_ms           = 3000
measure_time_ms                    = 30000
wait_time_ms                       = 500
evaluate_deceleration_listvalue    = '-0' # for evaluation of 'a_Veh_x'
testcase_sequence                  = 'Activation_before_IgnitionOff'
MM6_option                         = @('DISCARD_TO')
```

Figure 9. AVH scrip (excerpt)

CONTROLLED DECELERATION FOR PARKING BRAKE (CDP) – it is a Value-Added Function (VAF) that allows the driver to decelerate the vehicle in a controlled manner using the electronic parking brake (EPB) button [9]. The system decelerates by activating various actuators — hydraulic (via ESC) or electric generators (in EVs) — based on a deceleration target provided by the ESC. The Figure 9 describes the connection of electrical components to achieve the specific function.

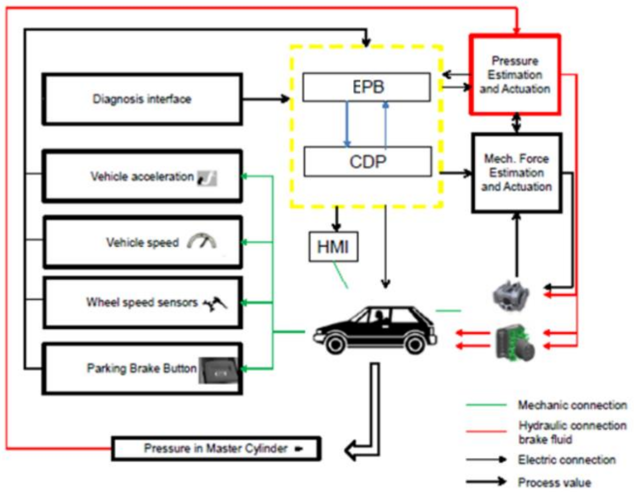


Figure 10. CDP functional topology.

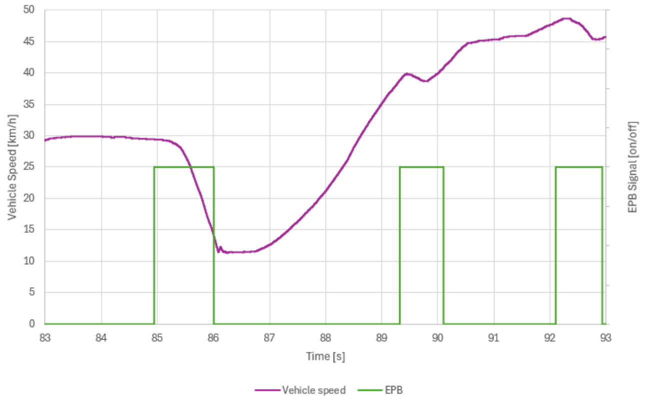
Although not designed for emergency braking, the driver initiates the deceleration by pressing and holding the EPB button. See Graphic 2. The ESC then manages the deceleration, ensuring a smooth reduction in speed.

Pressing the accelerator or releasing the EPB button will override the function. Activation requires an operational EPB button and vehicle speed above a set threshold.

Maintaining the same vehicle and test track configuration as in the earlier AVH tests, the following section details the results obtained for the CDP function.

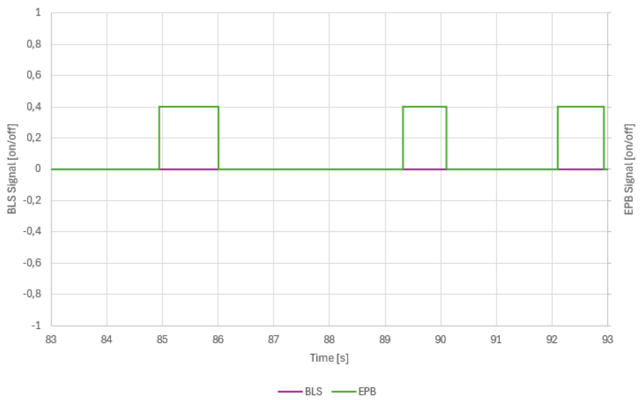
The vehicle is moving at a speed of approximately 30 km/h. At 85 seconds, the EPB button is activated by the driver. After releasing the EPB (by pressing the accelerator pedal), the vehicle resumes acceleration.

Two other simulations are performed at 89 seconds and 92 seconds. This demonstrates that the CDP provides additional safety to the driver in emergency situations or hydraulic brake system failure. The signal sent to the brakes is generated by the ESC.



Graphic 2. EPB actuation.

For better understanding, the following Graph 3 shows that the brake pedal was not activated by the driver (the BLS signal remains at 0). The EPB simulations are visible at three points in time.



Graphic 3. EPB and BLS signals.

In situations where the speed and deceleration are higher, the ESC will act in a complementary manner by hydraulically actuating the braking system. This will generate greater comfort during braking, reducing the stopping distance.

Other VAFs

In addition to CDP and AVH, the electronic stability control and electronic parking brake may cooperate in other Value-Added Functions (VAFs) to enhance vehicle safety and convenience. These include trailer stability control (TSC), where the EPB aids in mitigating trailer sway; hill-start assist (HSA), where the EPB can provide temporary hold on slopes; and automatic parking systems, where the EPB ensures secure immobilization upon completion of the parking maneuver.

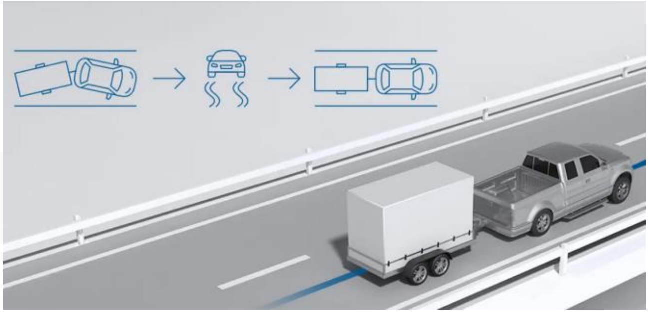


Figure 11. TSC.

In electromechanical braking systems prevalent in electrified vehicles, the EPB can function as a critical backup mode in the event of electrical failures. Should the primary braking system experience a loss of power or a malfunction in its electronic components, the EPB can be engaged to provide a redundant means of deceleration and immobilization.

Conclusion

In conclusion, the evolution of braking systems represents a continuous advancement in vehicle safety and functionality, culminating in the sophisticated electronic parking brake. By replacing traditional manual actuation mechanisms, the EPB not only simplifies operation but also unlocks a range of possibilities for integration with other active safety systems, such as electronic stability control.

The versatility of the EPB be placed in its ability to act in conjunction with other technologies, optimizing vehicle response in diverse situations. Whether providing secure immobilization after emergency braking, assisting in trailer stabilization, or serving as a vital component in autonomous parking systems, the EPB demonstrates a crucial role in promoting vehicle safety.

Therefore, the EPB transcends the mere function of parking, transforming into a central element of modern mobility. Its integration capabilities and the precision of its operation contribute significantly to driver safety and convenience, solidifying it as a fundamental component in contemporary vehicles.

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