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COMPARATIVE ANALYSIS OF ELECTRIC VEHICLE BATTERY TECHNOLOGIES: PERFORMANCE, SAFETY, AND SUSTAINABILITY

Alimnazarov Adkham
Tashkent State Technical University Master's student
alimnazarovadham0@gmail.com
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Abstract. This article examines the main faults that occur in automotive braking systems, their causes, diagnostic methods, and repair procedures. The technical condition of the braking system is one of the key factors determining vehicle safety. Faults in brake mechanisms, hydraulic or pneumatic actuators, brake fluid, and electronic control components can increase stopping distance, destabilise vehicle movement, and reduce braking effectiveness. The article discusses the importance of visual inspection, diagnostic measurements, brake-system testing, and electronic system checks in identifying faults. Practical recommendations are also provided for organising maintenance and repair work effectively.

Keywords: automobile, braking system, fault, diagnostics, brake pad, brake disc, hydraulic actuator, pneumatic actuator, ABS, maintenance.

1. INTRODUCTION. The braking system is one of the principal vehicle safety systems. It is designed to reduce vehicle speed, bring the vehicle to a controlled stop, and hold it stationary when parked. In modern vehicles, effective braking depends not only on the mechanical condition of the brake components but also on the proper operation of the hydraulic or pneumatic actuator, the electronic control units, and the adjustment of the brake mechanisms.

During vehicle operation, the braking system is exposed to substantial mechanical, thermal, and dynamic loads. During braking, the vehicle's kinetic energy is converted mainly into heat within the brake mechanisms. Consequently, the temperature of brake discs, drums, pads, and related components increases. Repeated or prolonged braking may cause wear of working surfaces, changes in material properties, and a reduction in braking performance.

Brake-system faults may result from normal wear, improper operation, failure to follow maintenance intervals, the use of low-quality replacement parts, and environmental factors. For example, deterioration of brake-fluid properties, air entering a hydraulic circuit, or brake mechanisms becoming seized can significantly impair system performance.

Timely identification of braking-system faults is essential for improving vehicle operational reliability, reducing repair costs, and lowering the risk of road traffic incidents.

The aim of this article is to systematically analyse common faults in automotive braking systems, identify their causes, describe diagnostic methods, and substantiate effective technical solutions for rectifying them.

2. MATERIALS AND METHODS. The study is based on an analysis of brake-system design and operating principles, maintenance requirements, and the fundamental methods used to diagnose vehicles. The analysis considers disc and drum brakes, hydraulic and pneumatic actuators, parking brakes, and the operating characteristics of anti-lock braking and other electronic control systems.

The fault-diagnosis methodology includes the following methods:

Visual inspection. Brake-fluid leakage, damage to pipes and hoses, brake-pad wear, disc or drum deformation, corrosion, and the condition of fasteners are examined.

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Functional checks. Brake-pedal travel, resistance and return, parking-brake operation, and vehicle directional stability during braking are assessed. These checks must be performed under safe conditions and in accordance with the vehicle manufacturer's instructions.

Measurement and test-bench diagnostics. A dedicated brake tester is used to measure braking force at individual wheels, differences in braking force, and other relevant parameters. The results are compared with the applicable technical requirements for the vehicle.

Electronic diagnostics. Fault codes in ABS and other electronic control systems are retrieved using a diagnostic scanner. Wheel-speed sensors, electrical circuits, the control unit, and the hydraulic modulator are then checked.

Cause-and-effect analysis. Potential causes are identified from the observed symptoms and then verified through additional tests.

This methodology makes it possible to identify faults not only from their visible symptoms but also by considering the underlying technical causes. The article is analytical in nature; it does not report independent laboratory or road-test results.

3.RESULTS AND DISCUSSION. The analysis indicates that braking-system faults can be grouped into problems involving mechanical components, actuator elements, and electronic control devices.

Faults in Brake Mechanisms. One of the most common faults in disc brakes is brake-pad wear. When the friction lining wears beyond the permitted limit, the contact conditions between the pad and disc change. Metal-to-metal contact and reduced braking effectiveness may occur. This condition can also cause noise during braking.

Uneven brake-disc wear, overheating, or a reduction in disc thickness below the manufacturer's minimum specification are also serious faults. Deep scoring, cracks, and unacceptable deformation of the disc may interfere with the consistent transmission of braking force. To rectify the fault, disc thickness and condition are measured; the disc and pads are replaced when required, in accordance with the manufacturer's specifications.

In drum brakes, common problems include worn brake shoes, weakened return springs, leakage from the wheel cylinder, and a seized adjustment mechanism. These faults may cause wheel overheating, reduced braking force, or failure of the brake to release fully. Repair involves cleaning the mechanism, replacing worn components, and carrying out the required adjustments.

Faults in Hydraulic Actuation. In a hydraulic braking system, an excessively soft brake pedal or a pedal that gradually sinks when held down may indicate air in the system, fluid leakage, or loss of internal sealing in the master cylinder.

A low brake-fluid level may be associated with leakage, brake-pad wear, or other conditions that require inspection. A significant drop in fluid level must not be treated as normal. Hydraulic pipes, joints, cylinders, and calipers should be carefully examined.

Air entering the hydraulic circuit impairs pressure transmission. As a result, pedal travel may increase and braking force may decrease. After the source of the fault has been corrected, the system must be bled according to the manufacturer's procedure. Brake fluid must be selected to match the specification required for the particular vehicle.

Faults in Pneumatic Braking Systems. In pneumatic braking systems used on trucks and buses, the compressor, air reservoirs, pressure regulator, pipes, brake chambers, and control valves are essential components.

Air pressure below the required level may be caused by reduced compressor output, air leakage, a faulty pressure regulator, or improper operation of the condensate-drainage system. Air leakage reduces the system's ability to maintain the specified pressure.

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Diagnosis involves monitoring pressure readings, inspecting pipes and connections, and locating leaks using an appropriate method. Defective valves, hoses, and other components are repaired or replaced. Monitoring moisture in the air system and checking the condition of the air dryer are also important.

Faults in Electronic Control Systems. In an ABS, damage to a wheel-speed sensor, broken wiring, corroded electrical contacts, or contamination of the tone ring may cause the system to malfunction. The warning indicator on the instrument panel may illuminate as a result.

A diagnostic scanner is used to retrieve fault codes, after which the sensors, electrical circuits, and relevant mechanical components are inspected. Replacing a component solely on the basis of a fault code is not appropriate, because the same code may be triggered by different underlying causes.

1Table. Common Faults and Corrective Measures

Fault symptom	Possible cause	Corrective action
Soft brake pedal	Air in the system or fluid leakage	Repair the leak and bleed the system
Increased stopping distance	Worn pads, a faulty mechanism, or road conditions	Inspect the mechanisms and replace worn components
Vehicle pulls to one side during braking	Unequal braking force between wheels	Inspect the caliper, pads, hoses, and brake mechanisms
Squealing during braking	Pad wear, contamination, or defects on the disc surface	Inspect friction surfaces and replace components as necessary
Excessive wheel temperature	Brake drag or a seized caliper	Repair the caliper and the brake-release mechanism
Reduced brake-fluid level	Leakage or another technical fault	Inspect the system and rectify the cause
ABS warning light illuminated	Sensor, electrical circuit, or control-system fault	Perform electronic diagnostics and repair the identified fault
Pressure loss in a pneumatic system	Air leakage or compressor malfunction	Locate and repair leaks; inspect the compressor and valves

The symptoms listed in the table are intended for preliminary diagnosis. A final diagnosis must be based on appropriate measurements and inspections.

The analysis shows that faults within a braking system may be interrelated. For example, uneven brake-pad wear may be caused not only by the properties of the friction material but also by seized caliper guide pins, a malfunctioning wheel cylinder, or uneven hydraulic-pressure transmission. Therefore, repairs should not be limited to replacing the visibly damaged component; the underlying cause must also be identified.

Visual inspection is a quick and convenient diagnostic method, but it cannot reveal every hidden fault. For example, internal seal failure in the master cylinder may occur without visible external fluid leakage. In such cases, functional tests and specialised procedures recommended by the manufacturer are required.

A brake test bench enables objective assessment of braking force at individual wheels. This is particularly useful for identifying unequal braking force, vehicle pull to one side, or insufficient operation of the brake mechanisms. For electronic systems, information obtained from a diagnostic scanner should be assessed alongside the results of mechanical inspections.

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A preventive approach to brake maintenance is highly important. Regular inspection of pads and discs, replacement of brake fluid at the intervals specified by the manufacturer, and monitoring of pressure and leakage in pneumatic systems help prevent faults.

The quality of replacement parts, correct installation procedures, and compliance with specified tightening torques are also essential. During assembly, only manufacturer-approved lubricants should be used where required; friction surfaces must not be contaminated with lubricant, and system integrity must be checked.

Before a vehicle is returned to service after repair, the completed work must be inspected. Pedal operation, the absence of fluid or air leaks, and the functional condition of the braking system must be assessed in accordance with the manufacturer's instructions. A vehicle with a serious braking-system fault must not be driven on public roads until the fault has been rectified.

CONCLUSION. Faults in automotive braking systems can occur due to the wear of mechanical parts, problems in hydraulic or pneumatic systems, and failures of electronic components. These faults can reduce braking efficiency and make driving unsafe. Regular inspection and timely maintenance help identify problems early and prevent serious failures. Visual inspection, functional tests, measurements, and electronic diagnostics are useful for finding faults. When repairing the braking system, damaged parts should be replaced, and the causes of the faults should also be identified and corrected. Regular checks of brake fluid, pipes, brake pads, discs, and electronic sensors help keep the system in good working condition. After repairs, the braking system must be checked to ensure that it works properly and safely. In conclusion, proper maintenance, modern diagnostic tools, and timely repairs help improve braking performance, extend the service life of the braking system, and ensure vehicle safety.

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