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FUNCTION, DESIGN AND OPERATING PRINCIPLE OF AUTOMOTIVE BRAKING SYSTEM

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Abstract
This article analyzes the functional tasks, design features and operating principles of the automotive braking system. The braking system is considered one of the most essential mechanical systems ensuring vehicle safety and maneuverability. The study examines the structural characteristics of hydraulic, pneumatic, mechanical and electronic braking systems, as well as the operational mechanisms of modern safety systems such as ABS and EBD. As a result of the work, the main factors affecting the efficiency of the braking system have been identified, and prospects for system improvement have been outlined.

Keywords: Braking system, hydraulic brake, pneumatic brake, ABS, disc brake, drum brake, braking force, safety.

Introduction

Relevance of the problem. Vehicle safety, reliability and efficient operation depend on many factors, among which the most crucial is the braking system. The braking system is considered one of the most important factors in ensuring traffic safety, since it serves to stop the vehicle, reduce its speed or hold it stationary.

According to statistical data, one of the main causes of road traffic accidents is a malfunction or inefficient operation of the braking system. Therefore, an in-depth study of the structural features, operating principles and influencing factors of the braking system is an important scientific and technical task.

Aim and objectives of the research. The main aim of this article is to systematically study and analyze the functional tasks, types, design features and operating principles of the automotive braking system.

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The main objectives of the research are:

- To clarify the main functions of the braking system;
- To analyze the types of braking systems and their structural features;
- To describe the operating principle of the braking system;
- To study the operational mechanism of modern safety systems (ABS, EBD);
- To identify factors affecting the efficiency of the braking system.

Scientific novelty of the research. The scientific novelty of this work lies in the comprehensive analysis of the braking system — from functional, structural and operational perspectives. The study presents an integrated examination of the classification of braking systems, their integration with modern technologies, and their impact on safety.

LITERATURE REVIEW

Research on braking systems has been conducted in several directions. The first direction focuses on improving the design of braking mechanisms, while the second direction is devoted to the development of electronic control systems (ABS, ESP, EBD).

Scientific literature provides a detailed description of the main types of braking systems — hydraulic, pneumatic and mechanical systems. The hydraulic system is mainly used in passenger cars, while the pneumatic system is used in heavy-duty trucks and buses.

Modern research has specifically studied the problem of brake disc overheating. Studies show that during prolonged or repeated braking, heat accumulation in the brake discs reduces system efficiency and increases the risk of emergency situations.

However, the existing literature lacks comprehensive and systematic studies of the functional tasks of the braking system in the IMRAD format. Filling this gap determines the relevance of this study.

MATERIALS AND METHODS

Object of research, The object of the research is the braking systems used in modern passenger cars and trucks. In particular, the structural elements of hydraulic, pneumatic and electronic braking systems and their interrelationships have been analyzed.

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Research methods. The following methods were used in the research:

- **Analysis and synthesis method** — for studying the elements of the braking system both individually and as a whole;
- **Comparison method** — for comparing different types of braking systems;
- **Observation and description method** — for explaining the operating principle of the system;
- **Logical modeling** — for explaining the physical mechanism of the braking process.

Theoretical basis. The operating principle of the braking system is based on the law of conservation of energy. The kinetic energy of the vehicle is converted into heat energy through friction in the brake mechanisms. The friction process occurs in two places:

1. Between the brake pads and the drum (or disc);
2. Between the tire and the road surface.

The braking force (F_t) is expressed by the following formula:

$$F_t = \mu \times N$$

where:

- μ = coefficient of friction;
- N = clamping force of the brake pad on the disc (or drum).

RESULTS

Main functions of the braking system. According to the results of the analysis, the automotive braking system performs the following main functions:

№	Function	Description
1	**Speed reduction**	When the driver presses the brake pedal, the vehicle speed decreases
2	**Complete stopping**	The system completely stops the rotation of the wheels
3	**Holding on inclines**	The parking brake prevents the vehicle from moving on slopes
4	**Emergency stopping**	Ensures fast and safe stopping in unexpected hazardous situations
5	**Improved maneuverability**	Creates convenience for the driver by enabling speed control

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Types of braking systems. The analysis revealed that braking systems are divided into four main types:

Hydraulic braking system. This is the most common type of braking system, used mainly in passenger cars. Pressure is transmitted through brake fluid. Advantages include simple design, efficiency and ease of maintenance.

Pneumatic braking system. This system operates using air pressure. It is mainly used in trucks, buses and trains. It provides powerful braking but is more complex and requires more technical maintenance.

Mechanical braking system. Braking force is transmitted directly through cables or mechanical levers. It is mainly used for parking brakes.

Electronic braking system (ABS). Modern vehicles are equipped with electronically controlled braking systems. The ABS system prevents wheel lock-up during braking, which maintains vehicle maneuverability.

Design of the braking system. The braking system consists of the following main structural elements:

№	Component	Function
1	**Brake pedal**	Pressed by the driver to initiate the braking process
2	**Master brake cylinder**	Generates pressure in the brake fluid
3	**Brake pipes and hoses**	Transmit brake fluid to the brake mechanisms at the wheels
4	**Brake mechanisms (calipers)**	Located at the wheels and directly provide stopping action
5	**Brake pads**	Provide friction to slow down wheel rotation
6	**Discs or drums**	Serve as friction surfaces

Physics of the braking process. During braking, the kinetic energy of the vehicle is converted into heat energy. The complete stopping time can be expressed by the following formula:

$$T = t_1 + t_2 + t_3$$

where:

- t_1 — driver's perception and reaction time to danger (0.4–1.5 seconds);
- t_2 — signal transmission time in the brake system (≈0.2 seconds for hydraulic; ≈ 0.3 seconds for mechanical; 0.6–0.7 seconds for pneumatic);
- t_3 — actual stopping time after braking begins.

When evaluating braking system efficiency, the slip coefficient (λ) is an important parameter:

$$\lambda = (v - v_w) / v \times 100\%$$

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where:

- v = vehicle linear speed;
- v_w = wheel rotational speed.

When λ = 100%, it corresponds to a state of fully locked wheels. This significantly reduces braking efficiency.

DISCUSSION

Factors affecting braking system efficiency. Research results show that braking system efficiency depends on several factors:

1. Vehicle speed — stopping distance increases quadratically with increasing speed;
2. Road surface condition — the friction coefficient decreases on wet, icy or contaminated roads;
3. Tire condition — tread depth and tire air pressure play a significant role;
4. Technical condition of the braking system — wear of brake pads, quality and volume of brake fluid;
5. Vehicle mass — the stopping distance of a loaded vehicle increases.

Comparative analysis of disc and drum brakes

Parameter	Disc brake	Drum brake
Cooling efficiency	High	Low
Resistance to overheating	High	Low
Manufacturing cost	High	Low
Ease of maintenance	Convenient	Complex
Resistance to contamination	Medium	High

Disc brakes have higher efficiency, are used more frequently and have better cooling capabilities. However, they can sometimes face overheating problems.

Advantages of the ABS system

The Anti-lock Braking System (ABS) has the following advantages:

- Prevents wheel lock-up during emergency braking;
- Maintains vehicle maneuverability;
- Reduces vehicle swerving during braking;

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- Increases braking efficiency on wet and slippery roads.

The ABS operates on the following principle: the electronic control unit constantly monitors speed sensor readings. If a wheel starts rotating slower than the others (indicating impending lock-up), the control unit reduces the pressure in the brake system of that wheel and restores wheel rotation. This process can be repeated up to 15 times per second.

Modern trends

In recent years, the following directions in braking system improvement have been observed:

Materials science — introduction of ceramic and carbon-ceramic brake discs;

Electronic safety systems — integration of ABS, EBD, ESP, BAS and similar systems;

Energy recovery — use of regenerative braking systems in hybrid and electric vehicles;

Autonomous emergency braking — development of systems that automatically detect obstacles and perform emergency braking.

CONCLUSION

This article systematically examined the functional tasks, types, design features and operating principles of the automotive braking system. The research led to the following main conclusions:

The braking system is one of the most important safety systems in a vehicle. Its main functions are speed reduction, complete stopping, holding on inclines, emergency stopping and improving maneuverability.

Braking systems are classified structurally into hydraulic, pneumatic, mechanical and electronic types. The hydraulic system is widely used in passenger cars, while the pneumatic system is used in heavy trucks and buses.

The efficiency of the braking system depends on factors such as vehicle speed, road surface condition, tire condition, technical condition of the system, and vehicle mass.

The ABS system prevents wheel lock-up during emergency braking, which helps maintain vehicle maneuverability and significantly increases safety.

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Modern trends in braking system development are moving towards integration with electronic safety systems and the introduction of new materials (ceramics, carbon-ceramics).

Practical recommendations:

- Regular technical inspection and maintenance of the vehicle braking system is necessary;
- The wear level of brake pads and discs should be regularly monitored;
- The level and quality of brake fluid should be checked within specified intervals;
- In vehicles equipped with ABS, the brake pedal should be pressed continuously and firmly during emergency braking (the system automatically provides pulsation).

Recommendations for future research:

- Continue research on optimizing heat dissipation in braking systems;
- Study methods to improve the efficiency of regenerative braking systems;
- Improve emergency braking algorithms for autonomous vehicles;
- Conduct experimental research on braking system reliability under different climatic conditions.

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