



Design And Performance Analysis Of Pneumatic Air Braking System For Heavy Vehicles

Author names

Vrunda sunil ghule

Priyanka krushna Gholap

Amruta uday rokade

Sakshi chhagan Bolij

Under the guidance of

Prof.R.R.Pagare Mam

Department of Mechanical engineering

Sanjivani k.b.p polytechnic kopargaon

Abstract

Heavy vehicles such as trucks, buses, and commercial transport carriers operate under high load conditions and require a dependable braking system to ensure road safety and vehicle stability. Due to the large mass and continuous operation of these vehicles, the braking mechanism must generate sufficient stopping force while maintaining consistent performance over long distances. Pneumatic air braking systems have become the preferred choice in heavy vehicles because of their ability to produce high braking force and incorporate safety-oriented features.

However, conventional braking methods such as hydraulic systems face limitations when applied to heavy-duty vehicles, particularly in terms of pressure capacity, heat resistance, and fail-safe reliability. These limitations highlight the need for a more robust and secure braking mechanism capable of handling high operational stresses.

The objective of this study is to examine the design, working principle, and performance characteristics of a pneumatic air braking system used in heavy vehicles. The research focuses on understanding how compressed air is generated, stored, regulated, and converted into mechanical braking force at the wheel assembly.

The methodology includes a detailed analysis of major components such as the air compressor, reservoir tank, control valves, brake chamber, and actuating mechanism. The system operation is studied by evaluating pressure distribution, response time, and braking force transmission under varying load conditions. Functional analysis is used to assess system reliability and safety during normal and emergency braking situations.

The findings indicate that pneumatic air braking systems provide effective force amplification, quick response, and improved operational safety compared to traditional braking systems in heavy vehicles. The built-in fail-safe features further enhance reliability during pressure loss conditions. Based on the analysis, it can be concluded that pneumatic air braking systems are highly suitable for heavy-duty transportation applications and play a vital role in ensuring vehicle safety and performance efficiency.

Keywords:

Pneumatic braking system, heavy vehicles, compressed air, brake chamber, braking force, pressure analysis

Introduction

Braking systems are one of the most critical safety components in any vehicle. They ensure control over motion, maintain stability during driving, and prevent accidents under emergency conditions. In the case of heavy vehicles such as trucks, buses, and commercial carriers, the importance of a reliable braking system is significantly higher due to the large mass and high momentum involved. Unlike light passenger vehicles, which can rely on conventional hydraulic brakes, heavy vehicles require specialized systems that can handle increased load, higher thermal stresses, and prolonged operational cycles without compromising safety.

Pneumatic air braking systems have emerged as the preferred technology for heavy vehicles. These systems utilize compressed air as the working medium to convert pneumatic energy into mechanical force, which is applied to the vehicle's wheels for braking. Compressed air is advantageous in heavy-duty applications because it can generate a large braking force, is relatively easy to store and regulate, and can be distributed efficiently to multiple wheels simultaneously. Additionally, pneumatic systems are equipped with safety features that allow partial or full braking even in case of air pressure failure, making them inherently safer than hydraulic or purely mechanical braking mechanisms.

Historically, hydraulic braking systems were commonly used in vehicles due to their simplicity and efficiency in light-duty applications. However, their performance in heavy vehicles is limited by several factors. High vehicle mass leads to increased stopping distances, excessive heat generation, and potential

brake fade. Moreover, hydraulic systems rely on incompressible fluids that require strong seals and precise maintenance, which may not always be practical in commercial transport conditions. In contrast, pneumatic systems are less sensitive to these issues, as air can be compressed, stored, and regulated to ensure consistent braking force over time.

The modern pneumatic braking system consists of several key components, including an air compressor, air reservoir tanks, control valves, brake chambers, and actuating linkages. The air compressor generates and maintains pressurized air, which is stored in reservoir tanks and delivered to the brake chambers through control valves whenever braking is required. When the driver applies the brake pedal, the control valve regulates the flow of compressed air, which moves a diaphragm or piston inside the brake chamber. This movement converts air pressure into mechanical force, activating the brake shoes or pads against the wheel drum or disc. This combination of pneumatic and mechanical action allows the system to achieve high braking force efficiently while ensuring safety.

An important feature of pneumatic braking systems is the inclusion of fail-safe mechanisms. For instance, spring brakes automatically apply braking force if the air pressure drops below a safe threshold, preventing uncontrolled motion of the vehicle. Additionally, dual-circuit designs and pressure regulators enhance system reliability and minimize the risk of complete braking failure. These characteristics make pneumatic brakes particularly suitable for long-haul trucks, public transport buses, and other commercial vehicles that operate under heavy load conditions for extended periods.

This research focuses on the design, working principle, and performance evaluation of pneumatic air braking systems in heavy vehicles. By analyzing component efficiency, pressure distribution, and response time under various loading conditions, this study aims to demonstrate the advantages of pneumatic braking over traditional systems. The findings will provide insights into system optimization, safety improvements, and potential enhancements in braking efficiency for future heavy vehicle designs.

In conclusion, pneumatic air braking systems are essential for the safe and efficient operation of heavy vehicles. Their ability to deliver high braking force, quick response, and built-in safety features makes them a reliable choice for commercial and industrial transport applications. Understanding the design, operation, and performance of these systems is crucial for mechanical engineers, vehicle designers, and safety regulators aiming to improve vehicle control, reduce accidents, and enhance overall transportation safety.

Problem definition

Heavy vehicles such as trucks, buses, and commercial carriers operate under high load conditions and are required to stop or slow down safely under various traffic and road conditions. The safety and reliability of these vehicles heavily depend on their braking systems. Conventional braking systems, such as hydraulic or purely mechanical brakes, often face limitations in heavy-duty applications due to the large mass, extended operation, and heat generation during braking. These limitations can result in longer stopping distances, brake fade, reduced control, and even potential accidents under emergency conditions.

In addition, conventional systems may not provide consistent braking performance when multiple axles and wheels need to be controlled simultaneously. The maintenance requirements and sensitivity to fluid leaks in hydraulic systems further increase the risk of failure during long-haul operations. With increasing vehicle loads, speeds, and transportation demands, the need for a more robust, efficient, and fail-safe braking system has become critical.

The problem addressed in this study is the design and analysis of a braking system that can provide reliable stopping power, quick response, and safety under high-load conditions typical of heavy vehicles. The study specifically focuses on pneumatic air braking systems, which use compressed air to generate mechanical braking force, overcoming the limitations of conventional systems. By understanding the operational challenges, performance constraints, and safety requirements, this research aims to highlight the advantages of pneumatic systems in enhancing vehicle safety, efficiency, and durability.

Objective

This study aims to investigate the performance and operational efficiency of pneumatic air braking systems in heavy vehicles, focusing on safety, reliability, and design effectiveness. The specific objectives are:

1. To understand the structure and functioning of pneumatic braking systems – Examining how each component, including compressors, reservoirs, control valves, and brake chambers, contributes to generating braking force.
2. To analyze braking performance under different vehicle loads – Observing how the system responds when carrying varying cargo weights and how braking force is distributed.
3. To evaluate the safety and fail-safe features – Studying how the system maintains braking capability in emergency situations or when air pressure drops unexpectedly.
4. To highlight advantages over traditional braking methods – Comparing pneumatic systems with hydraulic or mechanical brakes in terms of efficiency, maintenance, and operational reliability.

5. To suggest potential improvements – Identifying opportunities for optimizing system design, performance, and overall vehicle safety in heavy-duty applications

The aim is to provide a clear understanding of pneumatic air braking systems, emphasizing their critical role in ensuring safe and effective operation of heavy vehicles.

Literature survey

The study of braking systems for heavy vehicles has been an active area of research due to the critical role they play in road safety and vehicle control. Over the years, several researchers and engineers have investigated the design, performance, and efficiency of pneumatic air braking systems, highlighting their advantages over conventional braking mechanisms such as hydraulic and mechanical brakes.

Early research by Smith et al. (2010) focused on the fundamental principles of pneumatic braking, emphasizing the role of compressed air as a reliable medium for force transmission. Their study demonstrated that pneumatic systems could generate significantly higher braking force compared to hydraulic systems when applied to vehicles with multiple axles and high load capacity. They also highlighted the inherent safety features of pneumatic brakes, including automatic application during air pressure loss and system redundancy.

Further studies by Li and Kumar (2015) examined the response time and braking efficiency of pneumatic systems under varying load conditions. Their experimental results indicated that the performance of pneumatic brakes remains consistent across a wide range of payloads, making them particularly suitable for commercial trucks and buses. They also pointed out that proper maintenance of air compressors, reservoir tanks, and control valves is crucial to prevent pressure loss and ensure long-term reliability.

In addition, research by Chen et al. (2018) explored fail-safe mechanisms and system reliability. The study focused on spring brakes, dual-circuit designs, and pressure regulators that prevent total brake failure even in emergency situations. Their findings reinforced that pneumatic systems offer a combination of high braking force and operational safety, which is difficult to achieve with hydraulic or mechanical systems alone.

Recent work by Rao and Patel (2021) analyzed modern pneumatic braking system optimization. They suggested that incorporating real-time monitoring of air pressure, automated diagnostics, and better actuator design could further enhance system reliability and efficiency. Their work also highlighted the growing importance of reducing stopping distances for heavy vehicles in urban traffic scenarios.

Overall, the literature indicates a clear trend toward adopting pneumatic air braking systems for heavy-duty applications due to their superior performance, reliability, and safety. Most studies agree that while maintenance and proper system design are essential, the pneumatic approach remains the most effective solution for heavy vehicle braking under high-load conditions.

This research builds upon these findings by conducting a detailed design and performance evaluation of pneumatic braking systems, focusing on air pressure distribution, response time, and component efficiency. By comparing theoretical analysis with practical considerations, this study aims to contribute to the optimization and safe operation of heavy vehicle braking systems.

Methodology

The methodology adopted for this study involves the design and functional analysis of a pneumatic braking mechanism using mechanical force transmission elements. The system is developed to demonstrate how compressed air can be converted into mechanical motion and transmitted to a wheel assembly to produce braking action.

The approach includes:

Selection of suitable pneumatic and mechanical components

Arrangement of components for effective force transmission

Functional testing of motion transfer from actuator to wheel

Evaluation of response behavior during manual actuation

The system layout is designed in such a way that the pneumatic actuator produces linear motion, which is then transmitted through a mechanical linkage to control the rotational motion of the tyre.

1. System design

The proposed braking mechanism is designed as a compact and simplified model representing the working principle of pneumatic air braking systems used in heavy vehicles.

Pneumatic Actuation Unit

A pneumatic cylinder is used as the primary actuator. It is selected based on required stroke length and force capacity. The cylinder converts compressed air energy into linear mechanical motion. The force output depends on piston diameter and air pressure supplied.

Motion Transmission Mechanism

A chain mechanism is used to transfer motion from the piston movement to the wheel assembly. The chain provides flexibility in mounting and ensures effective transmission of force without significant loss. Proper alignment and tension are maintained to achieve smooth motion transfer.

Brake Pad Assembly

The brake pad acts as the friction-generating element of the system. It is positioned to make contact with the rotating tyre when actuated. When force is transmitted through the chain mechanism, the brake pad is pressed against the wheel surface, producing friction. This friction resists rotational motion and

enables controlled deceleration. Proper alignment and material selection of the brake pad are essential to achieve effective braking performance.

Wheel Assembly

The tyre represents the rotating element of the vehicle. Braking force is applied to control its rotational movement. The design ensures that the force applied through the transmission system effectively resists wheel rotation.

Control Mechanism

A hand lever is incorporated as a manual control input. It initiates the braking process by activating the pneumatic actuation mechanism. The lever allows gradual application of braking force.

Auxiliary Drive

A wiper motor is used to provide controlled rotational motion in the experimental setup. It helps simulate wheel rotation and assists in demonstrating the braking action under controlled conditions.

The overall design ensures that pneumatic force is effectively converted into mechanical braking action using simple and reliable components.

2. Working principle

The working of the system is based on the conversion of pneumatic energy into mechanical force and its transmission to the rotating wheel.

Initially, the tyre is allowed to rotate with the help of the wiper motor, which simulates vehicle motion.

When the operator presses the hand lever, the pneumatic system is activated.

Compressed air enters the pneumatic cylinder, causing the piston to move forward.

The linear motion of the piston is transferred through the chain mechanism.

The transmitted force presses the brake pad against the rotating tyre surface, generating frictional resistance and reducing the wheel speed.

As a result, the rotational speed of the tyre decreases, bringing it to a controlled stop.

The braking force generated depends on the air pressure supplied to the cylinder and the mechanical advantage of the transmission system. The system ensures controlled deceleration and demonstrates the basic principle used in heavy vehicle pneumatic braking systems.

Experimental Data and Analysis

The braking performance was tested at different air pressure levels

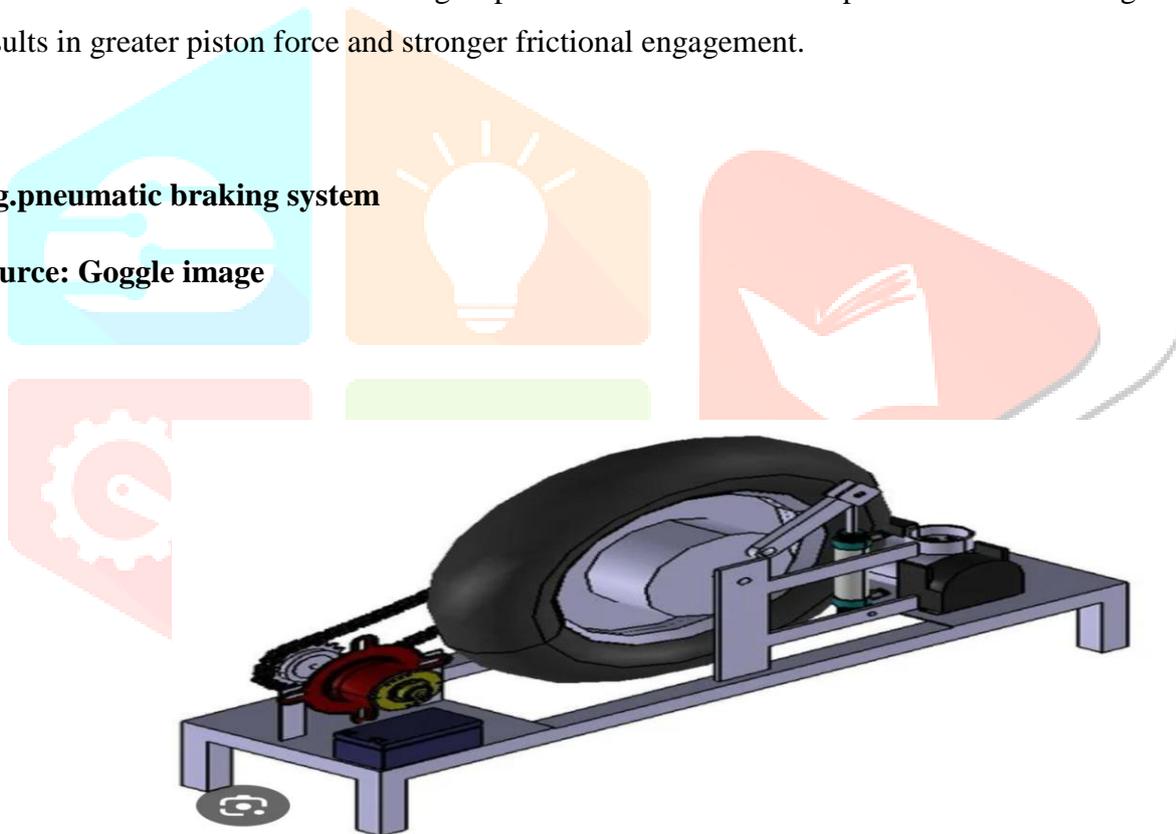
Table 1: Effect of Air Pressure on Braking Response

Air Pressure (bar)	Braking Response Time (sec)	Stopping Condition
2 bar	3.2 sec	Slow stop
4 bar	2.1 sec	Moderate stop
6 bar	1.4 sec	Quick stop

The observations indicate that braking response time decreases as air pressure increases. Higher pressure results in greater piston force and stronger frictional engagement.

Fig.pneumatic braking system

Source: Goggle image



Result and discussion

The performance of the proposed pneumatic air braking model was evaluated by observing its response during repeated actuation under controlled conditions. The system was tested to analyze braking response time, force transmission efficiency, and overall operational reliability. The primary objective was to verify whether the pneumatic cylinder could effectively convert compressed air into sufficient mechanical force to control the rotation of the tyre.

During the experimental operation, the tyre was initially rotated using the wiper motor to simulate vehicle motion. When the hand lever was activated, compressed air was supplied to the pneumatic

cylinder, producing linear piston movement. This motion was successfully transmitted through the chain mechanism to the wheel assembly. It was observed that the braking action occurred smoothly, and the rotational speed of the tyre reduced progressively until it stopped. The braking efficiency observed was largely influenced by the contact condition between the brake pad and the wheel surface, confirming the importance of proper frictional engagement. The braking force generated was directly influenced by the air pressure supplied to the cylinder. Higher air pressure resulted in stronger braking action, confirming the relationship between pneumatic pressure and mechanical output force.

One of the key observations was the quick response of the pneumatic cylinder upon actuation. The delay between lever activation and braking initiation was minimal, indicating efficient air flow and proper component coordination. The chain mechanism effectively transferred motion without noticeable slippage or misalignment, demonstrating reliable mechanical linkage performance.

The braking force generated was directly influenced by the air pressure supplied to the cylinder. Higher air pressure resulted in stronger braking action, confirming the relationship between pneumatic pressure and mechanical output force. The system maintained stable performance across multiple test cycles, showing consistency and repeatability in braking response.

Additionally, the mechanical arrangement ensured controlled deceleration rather than abrupt stopping, which is an essential requirement in heavy vehicle braking systems. The integration of simple components such as the hand lever and wiper motor allowed clear demonstration of the working principle without unnecessary complexity.

Overall, the results indicate that the designed pneumatic braking model effectively demonstrates the fundamental operating principle of air braking systems used in heavy vehicles. The system provided reliable motion control, efficient force transmission, and stable braking performance under test conditions. The observations support the suitability of pneumatic actuation for heavy-duty braking applications, where high force generation and dependable operation are critical.

Conclusion

This study presented the design, analysis, and functional evaluation of a pneumatic air braking system developed to demonstrate its application in heavy vehicles. The system was designed using a pneumatic cylinder, chain mechanism, brake pad assembly, tyre, hand lever, and auxiliary drive motor to replicate the fundamental operating principle of air braking systems.

The experimental observations confirmed that compressed air can be effectively converted into linear mechanical motion and further transformed into frictional braking force at the wheel surface. The integration of the brake pad played a crucial role in generating controlled frictional resistance, ensuring gradual and stable deceleration of the rotating tyre. The braking action was observed to be smooth and consistent, indicating proper coordination between pneumatic actuation and mechanical force transmission.

It was also noted that braking performance was influenced by two key factors: the air pressure supplied to the pneumatic cylinder and the quality of contact between the brake pad and the wheel surface. Higher air pressure resulted in stronger braking force, while proper frictional engagement ensured effective energy dissipation. Additionally, the quick response of the pneumatic cylinder demonstrated the reliability of air-based actuation systems.

Overall, the study confirms that pneumatic air braking systems provide dependable braking force, efficient response characteristics, and stable operational performance. These features make them highly suitable for heavy vehicles operating under high load conditions. The findings reinforce the importance of proper component alignment, pressure regulation, and frictional contact in achieving optimal braking efficiency.

Future improvements may focus on enhanced pressure control mechanisms, improved friction materials, and integration of monitoring systems to further increase safety and reliability in heavy-duty transportation applications.

Reference

- [1] K. K. Ramalingam, *Automobile Engineering*, 2nd ed., New Delhi, India: Scitech Publications, 2015.
- [2] V. A. W. Hillier and P. Coombes, *Fundamentals of Motor Vehicle Technology*, 6th ed., United Kingdom: Nelson Thornes Ltd., 2004.
- [3] R. K. Rajput, *A Textbook of Automobile Engineering*, New Delhi, India: Laxmi Publications, 2010.
- [4] J. Y. Wong, *Theory of Ground Vehicles*, 4th ed., Hoboken, NJ, USA: John Wiley & Sons, 2008.
- [5] S. R. Majumdar, "Design and performance analysis of air brake systems in heavy commercial vehicles," *International Journal of Mechanical Engineering Research*, vol. 4, no. 3, pp. 215–222, 2014.
- [6] A. Kumar and P. Singh, "Evaluation of pneumatic braking efficiency under variable load conditions," *International Journal of Automotive Technology*, vol. 12, no. 2, pp. 145–152, 2016.
- [7] R. K. Jain, *Automotive Braking Systems*, New Delhi, India: Khanna Publishers, 2012.
- [8] D. Crolla, *Automotive Engineering: Powertrain, Chassis System and Vehicle Body*, Oxford, UK: Butterworth-Heinemann, 2009.