Characteristics, application fields, and future development and challenges of shock absorbers

Jue Wang [*]

Leicester International Institute, Dalian University of Technology, Dalian, China

[*] Corresponding Author Email: jw856@student.le.ac.uk

Abstract. Vibrations potentially damage equipment and mechanical structures. To mitigate this potential harm, it is necessary to implement specialized vibration-damping equipment, engineering controls to minimize the transmission of vibrations, and the wearing of appropriate personal protective gear. These measures help safeguard the safety of both equipment and personnel while ensuring their normal operation and longevity. Nowadays, shock absorbers play a crucial role in various fields, mitigating external forces such as earthquakes and wind to protect equipment, structures, and individuals from the adverse effects of vibrations. This paper reviews the historical development of shock absorbers, spanning from the earliest friction dampers to the contemporary remotely controllable variants. This paper provides an overview of fundamental principles and diverse types of shock absorbers, including hydraulic shock absorbers, pneumatic shock absorbers, and magnetorheological shock absorbers. The applications of shock absorbers have been analyzed, emphasizing their significance in daily life. In addition, this paper underscores the future prospects of shock absorbers in environmental protection, sustainability, and their evolving role in safeguarding society.

Keywords: Vibration; Shock absorbers; Safety; Sustainability.

1. Introduction

Vibrations can potentially pose hazards to machinery, engineering structures, and the human body. For instance, vibrations can lead to material fatigue, posing a threat to the lifespan of machinery, especially under high-intensity vibrations. Simultaneously, mechanical vibrations generate noise, which has adverse effects on the surrounding environment and the well-being of personnel [1]. Protecting equipment, structures, and individuals from the adverse effects of vibrations remains one of the most formidable challenges in contemporary mechanical engineering [2]. The shock absorber, also known as a dampener or suspension damper, is a critical component widely employed in automobiles, motorcycles, architectural structures, and various mechanical systems. Shock absorbers are first used on horse-drawn carriages, employing the simplest spring and damper structures, which continue to be utilized today. In the early 20th century, the advent of hydraulic shock absorbers significantly enhances damping effectiveness. With ongoing advancements in science and technology, various types of shock absorbers have been introduced. Today, applications of shock absorbers can be found across diverse industries. These devices not only ensure human safety and enhance comfort, but also extend the lifespan of equipment.

This paper delves into the development of shock absorber technology from early concepts to contemporary innovative applications, elucidating how it has shaped our modern world. This paper may offer a reference for the research of shock absorbers.

2. Fundamental Theory and Classification of shock absorbers

A fundamental concept in the theory of vibration is periodic oscillation. Achieving this phenomenon through the interplay of potential and kinetic energy conversion [2]. The principle of damping is typically described as: when an object is in motion, it experiences a certain level of damping, and this resistance slows down the object's velocity and increases the passage of energy. This feature explains the reason why free vibrations eventually decay [3]. Shock absorber can be classified into various types, such as hydraulic shock absorber, pneumatic shock absorber, damper, and so on.

2.1. Hydraulic Shock Absorber

For hydraulic shock absorber, there are two cylinders differing in diameter that make up the external component in this system, as shown in Fig 1. The gas is nitrogen under low pressure. When the shock absorber undergoes extension or compression, the piston attached to a rod also extends or compresses. Within the shock absorber, the hydraulic fluid flows back and forth through small valves, and the internal friction between fluid molecules and the friction between the fluid and the small openings create damping motion, thus reducing vibrations. The hydraulic shock absorber utilizes the viscosity and fluid damping properties of the liquid. In many suspension systems, there exists a significant distinction compared to this particular suspension system: almost all other suspensions incorporate a spring. Its primary function is to absorb and dissipate external impacts, providing a smoother environment. The principle is that when a vehicle experiences an impact, the spring compresses or extends, converting kinetic energy into elastic potential energy. Additionally, within the realm of automotive suspension systems, the spring assists in adjusting the vehicle's height. The spring serves multiple roles within suspension systems, enhancing the stability of various mechanical systems.

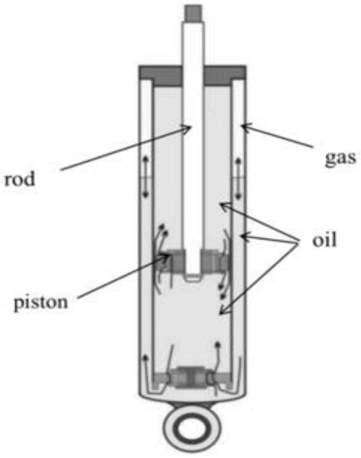

Fig 1. Model of hydraulic shock absorber [4].

Incorporating the foundation of hydraulic shock absorbers, engineers have developed an automatic shock absorber known as the Constant Damping Control (CDC) shock absorber. CDC has the capability to adjust damping levels in response to varying environmental conditions, thereby enhancing driving comfort. Typically, a CDC system comprises four main components: sensors, the Electronic Control Unit (ECU), control valves, and the liquid shock absorber itself. In the working process, sensor signals (including various types such as vehicle body acceleration sensors, wheel acceleration sensors, and lateral acceleration sensors, among others) or driver commands are transmitted for data processing by the central control system (ECU). The ECU carries out the necessary calculations and subsequently regulates the valve openings, thereby altering the flow of hydraulic fluid. This adjustment in fluid flow, in turn, modifies the damping characteristics of the shock absorber, ultimately leading to an enhancement in ride comfort.

2.2. Pneumatic Shock Absorber

The working mechanisms of pneumatic shock absorber and hydraulic shock absorber are fundamentally distinct. Pneumatic shock dampers employ an initially stable-pressure elastic chamber constructed from high-strength pressure-resistant materials. This chamber can compress gas, allowing the damper to convert impact forces into elastic potential energy, thereby significantly enhancing stability. As the impact force diminishes, the elastic chamber returns to its original state. Compared to liquid dampers, gas dampers possess both advantages and disadvantages.

Vibrations can potentially pose hazards to machinery, engineering structures, and the human body. For instance, vibrations can lead to material fatigue, posing a threat to the lifespan of machinery, especially under high-intensity vibrations. Simultaneously, mechanical vibrations generate noise, which has adverse effects on the surrounding environment and the well-being of personnel. Pneumatic shock absorbers offer several distinct advantages. Firstly, they are known for their cost-effectiveness. These shock absorbers are often more budget-friendly compared to their hydraulic counterparts, making them an attractive choice for various applications. Secondly, pneumatic shock absorbers provide stability due to their use of inert gases. These gases are less susceptible to changes in temperature and environmental conditions, ensuring consistent performance over time. Lastly, pneumatic shock absorbers are lightweight, which can be advantageous in applications where weight reduction is a priority. These qualities make pneumatic shock absorbers a cost-efficient, stable, and lightweight solution for damping and cushioning in diverse engineering and mechanical systems.

2.3. Magnetorheological Shock Absorber

Magnetorheological shock absorber, a cutting-edge variant of hydraulic shock absorbers, introduces a fascinating twist to conventional damping technology. It is similar to CDC shock absorber. These innovative shock absorbers employ a distinctive fluid containing minute iron particles, setting them apart from their traditional counterparts. What truly defines magnetorheological dampers is their ability to modify viscosity through the manipulation of a magnetic field. Structurally, these shock absorbers typically encompass three essential components: the magnetorheological unit, control circuitry, and sensors.

The core of magnetorheological dampers, the magnetorheological unit, consists of a closed-loop electromagnet in conjunction with the specialized fluid. The remarkable feature lies in the control circuitry, which enables precise adjustments of the electromagnetic field's magnitude and direction by regulating electric current. This strategic control directly influences the fluid's viscosity, allowing for real-time damping adjustments.

The integration of sensors within the system plays a pivotal role in ensuring that adjustments are responsive and optimized. These sensors continually monitor various parameters, including vehicle dynamics and road conditions, providing valuable input to the control circuitry. This seamless synergy between sensing and control empowers magnetorheological dampers to adapt rapidly to changing driving scenarios.

One of the standout advantages of magnetorheological dampers is their rapid response time, measured in milliseconds. This attribute is especially crucial in providing immediate damping adjustments, enhancing ride comfort, and ensuring vehicle stability. Furthermore, the high degree of controllability offered by these dampers allows for tailored suspension experiences across diverse driving conditions.

The adaptability of magnetorheological shock absorber extends across multiple domains. They have found prominent applications in the automotive industry, significantly improving ride quality, handling, and overall driving experience. Their presence is also felt in the realm of railway transportation, where they enhance train stability.

3. Application Fields of Shock Absorbers

The application of dynamic shock absorbers spans a wide range of fields with specific requirements related to stability, safety, and cost considerations. Different types of shock absorbers find their utility in various sectors, catering to specific needs. The most common application fields for shock absorbers are the automotive sector, mechanical engineering and construction.

3.1. Automotive Sector

An ideal shock absorber ensures continuous contact between the vehicle and the road surface [5]. Automobiles utilize the principle of hydraulic shock absorbers, where oil droplets inside the shock absorber chamber move reciprocally through various orifices into another chamber, creating friction and increasing the internal energy of the oil droplets. This process converts the vibration energy of the car into heat energy, thereby reducing impacts and improving ride comfort.

3.2. Mechanical engineering

In the mechanical engineering sector, the primary focus lies in improving production efficiency and cost-effectiveness. In industrial machinery, machines operate in high-stress environments, and the reduction of vibration and impact has become an indispensable component to prolong machine lifespan and reduce costs. Simultaneously, minimizing vibrations enhances machine stability and precision, thereby increasing product quality.

3.3. Construction

In the field of construction, the most common types of shock absorber are seismic shock absorbers and wind shock absorbers, both aiming at enhancing safety and reducing repair costs? These shock absorbers have frequent applications in high-rise buildings, laboratories, hospitals, and similar structures. High-rise buildings are designed to ensure safety, while laboratories and hospitals require precise instrument stability.

When selecting shock absorbers, in addition to ensuring their damping performance, attention should also be paid to their ability to self-recover and be reusable[6]. Pendulum-type shock absorbers offer this advantage. During an earthquake, a pendulum-type shock absorber's spherical mass starts swinging, converting seismic energy into kinetic energy, thus reducing seismic forces. Following an earthquake event, pendulum-type shock absorbers have the ability to automatically reset, allowing them to withstand multiple seismic events.

However, it is worth noting that pendulum-type shock absorbers require considerable space, making them unsuitable for buildings with limited space. Therefore, in the realm of shock absorbers, numerous challenges still exist.

4. Challenges and Future Development Trends

4.1. Environmental Challenge

Shock absorbers play a crucial role in enhancing the comfort and stability of vehicles. However, it's important to acknowledge the environmental concerns associated with their application. Firstly, the manufacturing process of shock absorbers involves the extensive use of resources, including metals, rubber, and fluids. The extraction and processing of these resources may lead to ecosystem disruption and energy consumption, posing environmental threats. Secondly, the usage of shock absorbers may contribute to emission issues. While shock absorbers themselves are not a primary source of pollution, the exhaust emissions generated by vehicle combustion engines are linked to air quality, which affects the performance of shock absorbers and vehicle stability. Additionally, the disposal of used shock absorbers may raise waste management concerns.

Addressing these environmental issues involves adopting more eco-friendly materials, manufacturing processes, and design methods for shock absorbers. Furthermore, automobile manufacturers are actively developing more energy-efficient vehicles and power systems to reduce the dependency on energy resources, thereby mitigating the environmental impact associated with shock absorbers. These measures aim to strike a balance between shock absorber technology and environmental sustainability.

4.2. Sustainable Challenge

Frequent motion and continuous road vibrations can gradually lead to the wear and tear of internal components within shock absorbers, thereby diminishing their ability to provide effective damping.

This may result in a deteriorated driving experience, reduced ride comfort, and suboptimal performance of the suspension system [7].

Furthermore, the seals and gaskets within shock absorbers may age over extended periods of use, potentially leading to fluid leakage. Fluid leaks can significantly compromise the performance of shock absorbers, making vehicles more susceptible to jolts and uneven road surfaces.

Another challenge arises from the potential adverse effects of external environmental factors on shock absorbers, such as harsh weather conditions, road salt, and corrosion. These elements can accelerate the wear and aging of shock absorbers, further shortening their lifespan.

To prolong the lifespan and maintain the performance of shock absorbers, regular inspections and maintenance are essential. Additionally, manufacturers are continually striving to develop more durable shock absorber materials and designs to address these durability issues [8]. The performance of shock absorbers directly impacts both driving safety and comfort, making the resolution of these issues crucial for automobile manufacturers and drivers alike.

4.3. Future Development

Potential advancements of shock absorbers reflect a growing emphasis on sustainability, efficiency, and versatility, aiming to enhance their performance and expand their applications across various industries.

Renewable Damping Systems: There may be a development of renewable damping systems capable of recovering and maximizing the utilization of dissipated energy. This could enhance sustainability in seismic mitigation [9].

Advanced Nanomaterials: Future shock absorbers might utilize cutting-edge nanomaterials, prioritizing environmental protection and material recyclability [10].

Compact Design: Shock absorber might not have the spatial requirements of traditional pendulum-style shock absorbers, becoming more compact without sacrificing their damping capabilities.

Interdisciplinary Collaboration: Advancements in shock absorbers may require collaborative efforts involving experts from various fields such as geology, materials science, mechanical engineering, and civil engineering.

Increased Intelligence and Remote Control: Future shock absorbers are expected to be more intelligent, potentially allowing for remote monitoring and control.

Diverse Applications: Shock absorbers are likely to find applications in a broader range of fields, including energy transportation to reduce vibration-related energy loss and cost, ensuring stability in medical and laboratory facilities, and even in aerospace engineering for the safety of rocket launches and landings. Military applications, such as firearm dampers to improve accuracy, may also become more prevalent.

5. Conclusion

This paper has delved into the significance and intricacies of shock absorbers in our lives. The evolution of these technologies is traced from the early friction shock absorbers used in horse-drawn carriages to the contemporary CDC shock absorbers with automated control. An overview of the principles and different types of shock absorbers have been provided in this article, including hydraulic shock absorbers, pneumatic shock absorbers, and magnetorheological shock absorber , highlighting their substantial impact in the field of construction. Shock absorbers are used not only in the automotive industry but also in engineering and architectural domains. They not only enhance the seismic resilience of structures but also profoundly influence the quality of life and work efficiency for people.

References

[1] Feng Chi, Jun Zhou, Qi Zhang, Yong Wang and Panling Huang. Avoiding the Health Hazard of People from Construction Vehicles: A Strategy for Controlling the Vibration of a Wheel Loader. International Journal of Environmental Research and Public Health, 2017.

[2] A. Velychkovych. Numerical Model of Interation of Package of Open Shells with a Weakly Compressible Filler in a Friction Shock Absorber. Engineering Solid Mechanics 10, 2022: 287-298

[3] S. H. Crandall. The Role of Damping in Vibration Theory. J. Sound Vib, 1970, 11(1): 3-18.

[4] M. Shams, R. Ebrahimi, A. Raoufi and B. J. Jafari. Cfd-fea Analysis of Hydraulic Shock Absorber Valve Behavior. International Journal of Automotive Technology, 2007, 8(5): 615−622.

[5] Łukasz Konieczny. Analysis of Simplifications Applied in Vibration Damping Modelling for a Passive Car Shock Absorber.Faculty of Transport, Silesian University of Technology, 2016.

[6] Suvash Chapain and Aly Mousaad Aly. Vibration Attenuation in High-rise Buildings to Achieve System-level Performance under Multiple Hazards. Engineering structures, 2019, 197(14)

[7] Zheng Peng[1], GAO Jingwei, Wang Ruichen, Dong Jianguo, Diao Jincheng. Review on the Research of Regenerative Shock Absorber. Automation & Computing, Newcastle University, 2018.

[8] Maun, J.A., Gard, S.A., Major, M.J. *et al.* Reducing Stiffness of Shock-absorbing Pylon Amplifies Prosthesis Energy Loss and Redistributes Joint Mechanical Work during Walking. *J NeuroEngineering Rehabil* 18, 2021, 143.

[9] Sang-Hoon Oh, Young-Ju Kim, Hong-Sik Ryu. Seismic Performance of Steel Structures with Slit Dampers. Engineering structures 31, 2009.

[10] Hasan Al-Rifaie and Wojciech Sumelka. The Development of a New Shock Absorbing Uniaxial Graded Auxetic Damper (UGAD). Materials, 2019.