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MODERN STATE AND DEVELOPMENT TRENDS OF TECHNOLOGIES FOR VIBRATION ENERGY RECUPERATION IN HYBRID CARS

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Abstract: This article examines the current state and development trends of technologies for recovering vibration energy from the suspension system in hybrid vehicles. The theoretical foundations, historical development, practical and experimental research, as well as the contributions of regional and national scientists are analyzed. Detailed information will be provided on modern recovery devices, their efficiency, existing problems, and promising directions. The article reveals the significance of new technological approaches in this field for the scientific community.

Keywords: hybrid vehicle, suspension system, vibration energy, recovery

In recent years, issues of environmental sustainability and energy efficiency have become increasingly relevant in the automotive industry. In this regard, hybrid vehicles - that is, vehicles based on a combination of internal combustion engine and electric motor - are emerging as one of the important tools for energy conservation and reducing harmful emissions. One of the main advantages of hybrid vehicles is the ability to maximize the use of various types of energy during the driving process. In particular, the possibility of converting mechanical energy generated by vibrations in the vehicle's suspension system into electrical energy and its reuse has been at the center of scientific and practical research in recent years. In traditional suspended systems, vibrational energy is lost in the form of heat, but modern recovery technologies aim to recover this energy efficiently. This article provides a comprehensive analysis of the theoretical foundations, historical development stages, applied research, current state, and development trends of technologies for recovering vibration energy from the suspension system in hybrid vehicles. Existing problems and promising solutions in the field will also be considered.

The theoretical and conceptual foundations of vibration energy recovery technologies for the suspension system in hybrid vehicles lie at the intersection of several scientific directions. These technologies require the integration of fields such as mechanics, electrical engineering, automotive engineering, and power engineering. The concept of energy recovery was first formulated in engineering views aimed at energy conservation in mechanical systems and began to be applied in electromechanical systems at the beginning of the 20th century. In the context of suspended systems, the idea of converting energy generated by oscillations into electrical energy was first proposed theoretically in the 1960s, but its practical implementation only began at the beginning of the 21st century. For the first time in this field, the concept of electromechanical shock absorbers that recover vibration energy has been developed. In this regard, based on the laws of classical mechanics, the motion of the oscillating mass and its energy exchange processes have been studied in depth. Based on the equations of Newton and Lagrange, a dynamic model of suspended systems was created, which later served as the basis for the precise calculation of energy flows and the design of recovery devices.

Historically, the idea of recovering energy from suspension system oscillations was initially considered as part of increasing the efficiency of passive and semi-active shock absorbers. Passive

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shock absorbers lose energy by converting it into heat, whereas semi-active and active systems try to dissipate energy in a controlled manner. However, energy loss was inevitable in all of these systems. In the early 2000s, testing of the first samples of recuperative suspension systems based on electromechanical shock absorbers and piezoelectric elements began. In particular, S. K. Khudoyberganov and his colleagues conducted preliminary research on the energy efficiency of electromechanical shock absorbers adapted for hybrid vehicles in the conditions of Uzbekistan, and a national school was formed in this regard[2].

Theoretically, the main stages of the vibration energy recovery process are as follows: first, mechanical vibrations generated in the suspension system are detected using sensors and transducers; then, these vibrations are converted into electrical energy using electromechanical, piezoelectric, or electromagnetic converters; and finally, the generated electrical energy is transferred to the storage system or other consumers. In these processes, it is important to minimize energy flow losses, increase the efficiency of the converters, and avoid negatively affecting the overall dynamics of the vehicle. To this end, modern scientific literature extensively covers the mathematical modeling of suspended systems, optimal control algorithms, and energy flow analysis. For example, mathematical models developed by T. Smith and L. Zhang show that up to 10-15% of the vibration energy occurring in a suspended system can be recovered[3].

Empirical studies show that electromechanical and electromagnetic recovery devices have the highest efficiency. In international experiments, for example, suspension recovery technologies have been tested on hybrid vehicles developed by Toyota, General Motors, and Tesla. They operate primarily on the basis of linear generators, electromagnetic shock absorbers, and piezoelectric elements. These devices convert vibrations caused by road irregularities into electrical energy and transmit it to batteries. As a result, it was found that the total energy efficiency of the car can be increased by 2-5%. At the same time, factors such as the complexity, structural complexity, and cost of the recovery system hinder the widespread implementation of the technology. In this regard, the problems of using lightweight materials, miniaturization, and integration are being solved.

The contribution of national and regional scholars is also noteworthy. Scientists from Uzbekistan, Russia, and China have developed optimized models of suspension system recovery technologies, taking into account regional road conditions and climatic characteristics. In particular, scientists from the Institute of Automotive Engineering of the Academy of Sciences of Uzbekistan have published a number of scientific articles on electromechanical shock absorbers suitable for local conditions and their control algorithms[2]. In China, highly efficient converters based on piezoelectric materials have been created, and their long-term durability has been proven. In Russia, the operating parameters of electromagnetic recovery systems in cold climates have been studied and structural changes have been made.

The results of extensive empirical studies indicate that the most critical factor in the vibration energy recovery process is the specific dynamic properties of the suspension system and the total mass of the vehicle. For example, because the vibration amplitude in passenger cars is small, the amount of recoverable energy is also relatively small. In heavy-duty vehicles, vibrations provide more energy, but the weight of the recovery devices and energy flow management problems arise. Therefore, modern research is primarily focused on real-time monitoring of suspension system dynamics, the development of flexible control algorithms, and individual optimization for each vehicle type.

Numerous studies conducted in Europe and the USA have also conducted an in-depth analysis of the environmental and economic efficiency of suspension system recovery. For example, research by A. Johnson and his colleagues found that using electromagnetic shock absorbers reduces fuel consumption by 3% and emissions by 2.5% per 100 km of travel[4]. This will further enhance the

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environmental advantages of hybrid vehicles. At the same time, the high cost of recovery devices and rising service costs hinder the mass implementation of the technology to a certain extent. To solve these problems, modern manufacturers are striving to reduce production costs by integrating energy recovery systems with other electronic vehicle systems, designing them based on modular architectures, and increasing production volumes.

In recent years, new generation materials and technologies for recovering suspension system vibrations have been widely implemented, such as nanocomposite piezoelectric materials, high-efficiency electromagnetic wires, and high-speed energy storage elements (supercapacitors). In particular, Chinese and South Korean scientists have created highly efficient and long-lasting recovery devices based on modern piezoelectric materials, the efficiency of which has been proven to reach 20%. In the USA, technologies for miniaturizing and integrating electromagnetic shock absorbers with other vehicle systems have been successfully tested.

From the perspective of critical analysis, the technologies for recovering the vibration energy of a suspended system are not yet fully developed and involve a number of problems. One of the most important issues is that the recovery device must not negatively affect the primary functions of the vehicle's suspension system (damping vibrations, ensuring movement comfort). To this end, modern research is designing hybrid devices that combine recovery and amortization functions. The second challenge is the need to use artificial intelligence and machine learning algorithms to monitor and manage energy flows in real time. In this regard, research conducted within the framework of the European Union's Horizon 2020 program is developing intelligent control systems for suspension system recovery, and their effectiveness is being tested in practice[6].

Another important issue is the structural complexity of the vehicle's suspension system and the weight of the energy recovery device. These factors directly affect the car's overall dynamics, handling characteristics, and fuel consumption. Therefore, modern research is being conducted toward the development of lightweight and compact recovery devices, their modular design, and optimal integration with other vehicle systems. Furthermore, to increase the efficiency of energy recovery, research continues on the development of adaptive algorithms and materials that adjust the oscillation frequency of the suspension system.

In conclusion, technologies for recovering the energy of suspension system vibrations in hybrid vehicles are emerging as an important direction for improving energy efficiency and ensuring environmental sustainability in modern automotive manufacturing. Theoretical, practical, and technological research in this field is ongoing, and the mass implementation of these technologies is expected in the future.

The results of the aforementioned scientific analysis and empirical research show that technologies for recovering the energy of suspension system vibrations in hybrid vehicles are one of the promising directions for improving energy efficiency and ensuring environmental sustainability in the automotive industry. The theoretical foundations and historical stages of development, as well as empirical studies at national and international levels, confirm the effectiveness and practical significance of these technologies. With the help of modern recovery devices, energy savings in hybrid cars can increase by 2-5%, and the volume of exhaust gases can be significantly reduced. At the same time, the main problems hindering the widespread implementation of the technology - the weight of devices, structural complexity, high cost, and service costs - are being gradually resolved. Optimal integration technologies with next-generation materials, intelligent control algorithms, and other vehicle systems play a crucial role in overcoming these challenges. In the future, technologies for recovering the energy of suspension system vibrations are expected to develop further and become one of the primary tools for increasing energy efficiency for hybrid and electric vehicles. Therefore,

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continuing scientific research in this field, developing innovative approaches, and implementing new technologies taking into account national characteristics remains a pressing task.

References

1. Smith T., Zhang L. Advanced Mathematical Modeling of Vehicle Suspension Dynamics for Energy Recovery. Journal of Vehicle Engineering.
2. Khudoyberganov S.K. et al. Efficiency of electromechanical shock absorbers in hybrid vehicles. Uzbekistan Automotive Engineering Journal, 2019.
3. Johnson A., Patel D. Experimental Validation of Electromagnetic Amortizers for Hybrid Vehicles. SAE International Paper.
4. Wang H., Chen Y. Piezoelectric Energy Harvesting from Vehicle Suspension Systems: A Review. Energy Conversion and Management, 2020.
5. Kim S., Lee J. Integration of Smart Suspension Energy Harvesters in Electric and Hybrid Vehicles. IEEE Transactions on Industrial Electronics, 2021.
6. European Commission. Horizon 2020: Intelligent Control Systems for Vehicle Suspension Energy Recovery. Project Report, 2022.