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INCREASING THE ENERGY EFFICIENCY OF HYBRID CARS USING ARTIFICIAL INTELLIGENCE-CONTROLLED REGENERATIVE SUSPENSION SYSTEMS

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Abstract: This article examines the role and effectiveness of regenerative suspension systems driven by artificial intelligence technologies in enhancing energy efficiency in hybrid vehicles. The study analyzes the theoretical, historical, and practical foundations, and examines the works of leading domestic and foreign scholars in this field. Based on empirical results, a profound analysis was conducted on the operating principles of modern suspended systems, the implementation of artificial intelligence algorithms, and their impact on energy-saving mechanisms. The article also highlights existing problems and promising directions.

Keywords: artificial intelligence, regenerative suspension system, hybrid vehicle, energy efficiency

Introduction

The modern automotive industry strives to implement new technologies to enhance energy efficiency, reduce emissions, and ensure environmental safety. Hybrid cars are becoming increasingly important, especially in terms of energy conservation and reducing emissions. In this field, issues regarding the recovery and efficient use of energy generated during the vehicle's movement are considered relevant. Regenerative suspension systems play an important role in this. The development of artificial intelligence technologies, in turn, allows for increasing the management efficiency of these systems and ensuring their optimal operation in real-time. This article provides a detailed analysis of the role, scientific foundations, and practical results of regenerative suspension systems driven by artificial intelligence in enhancing energy efficiency in hybrid vehicles. At the same time, scientific problems and promising directions are highlighted based on existing scientific research, historical development, and modern approaches.

Literature review

The issue of increasing the energy efficiency of hybrid vehicles is considered one of the most pressing issues in modern automotive manufacturing. Scientific research in this field, along with theoretical and practical approaches, ensures the continuous development of automotive technologies. The concept of a "regenerative suspension system" first appeared in the second half of the 20th century, when the study of the possibility of converting mechanical energy lost during vehicle movement into electrical energy and its reuse began. Initial research in this direction was primarily focused on improving the energy efficiency of passive and semi-active suspended systems. In classical theories, specifically based on Newton's and d'Alembert's principles, the fundamental mechanical properties of suspended systems, the causes of energy loss, and ways to reduce them have been extensively analyzed. Based on these principles, engineers identified the potential of passive suspension systems to reduce vehicle interaction with the road, dampen vibrations, and enhance driving comfort. However, the fact that passive systems lose energy only in the form of heat and lack the ability to recover it limited their efficiency.

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With the development of semi-active and active suspension systems, the issue of energy efficiency has risen to a new level. These systems have the ability to automatically change suspension system parameters in accordance with the vehicle's driving conditions and actively control vibrations. At the same time, active suspension systems have become capable of converting energy into electric current and storing it in batteries. Many foreign and domestic scientists have conducted research in this direction. For example, scientific schools in Japan, Germany, the USA, and South Korea have conducted extensive research on the design solutions, control algorithms, and energy recovery efficiency of regenerative suspended systems. At the same time, scientists in Uzbekistan have also achieved significant results in the development of energy-saving technologies, including variants of regenerative systems adapted for vehicles.

With the penetration of artificial intelligence technologies into the automotive industry, the management efficiency and energy efficiency of regenerative suspension systems have significantly increased. Using artificial intelligence, specifically machine learning, deep learning, and artificial neural networks, it has become possible to analyze the vehicle's driving conditions, road surface condition, speed, vibration, and other factors in real time and develop optimal control strategies. In this regard, there are both studies based on classical theory and practical research aimed at developing new modern algorithms. For example, control systems developed based on machine learning automatically adjust the suspension system parameters to maximize energy recovery during the vehicle's movement. This allows for an increase in energy efficiency by 10-15%[2].

From the perspective of theoretical and conceptual foundations, several important factors for the effective operation of regenerative suspension systems are identified. First, the mechanical design and materials of the suspension system determine its ability to regenerate energy. For example, the use of electromagnetic or piezoelectric elements increases the efficiency of converting energy into electric current. Secondly, for the optimal functioning of control algorithms, it is important to collect, process, and analyze data in real time. Artificial intelligence technologies, especially machine learning and adaptive control systems, play a key role here. The third aspect is maintaining a balance between energy efficiency and the comfort of the vehicle. This is because making the suspension system too rigid to maximize energy recovery can reduce the vehicle's driving comfort. Therefore, these factors must be taken into account when developing an optimal management strategy.

From a historical perspective, the evolution of regenerative suspension systems consisted of several stages. At the initial stage, in the 1960s and 1970s, research aimed at improving the energy efficiency of passive suspension systems was a priority. Later, in the 1980s, semi-active and active suspension systems appeared, through which it became possible to partially restore energy. Since the 1990s, research on electromagnetic and piezoelectric regenerative suspension systems has begun. During this period, electromagnetic regenerative shock absorbers were tested in the USA and European countries, and their energy recovery efficiency was evaluated. In the 2000s, with the development of artificial intelligence technologies, new paradigms for managing vehicle suspension systems emerged. In particular, systems developed based on machine learning and adaptive control algorithms have significantly increased energy efficiency. At the same time, Japanese companies such as Toyota, Nissan, and Honda, as well as German companies BMW, Mercedes-Benz, and Audi, began to widely implement regenerative suspension systems in hybrid and electric vehicles.

Scientists from Uzbekistan have also conducted a number of studies in this direction. In particular, scientists from the Tashkent State Technical University and the Andijan Machine-Building Institute conducted scientific work on modeling regenerative suspension systems for hybrid vehicles, developing control algorithms, and evaluating their efficiency. In these studies, methods for energy recovery based on electromagnetic shock absorbers and the adaptation of control algorithms using

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artificial intelligence were considered. In local conditions, it is of great importance to develop optimal management strategies, especially taking into account road surface irregularities, temperature, and other external factors. In this regard, the works of national scientists are distinguished by their focus on increasing the efficiency of regenerative suspension systems, taking into account regional characteristics[4].

According to the results of empirical studies, it has been determined that the energy efficiency of hybrid vehicles using regenerative suspension systems controlled by artificial intelligence is higher than that of traditional systems. For example, experiments conducted in the USA have proven that using electromagnetic regenerative suspension systems can reduce the total energy consumption of a vehicle by 8-12%. In Japan, adaptive suspension systems controlled by artificial intelligence have increased energy recovery efficiency by up to 15%. In experimental studies conducted under the conditions of Uzbekistan, it was also observed that as a result of delivering electrical energy from regenerative suspension systems to the vehicle's battery and using it in auxiliary systems, fuel consumption and exhaust gas levels decreased significantly. These results are attributed to the ability of artificial intelligence algorithms to select optimal control strategies in real time[5].

Control systems developed based on artificial intelligence algorithms, specifically reinforcement learning, evolutionary algorithms, and deep learning, adapt suspension system parameters to vehicle traffic, road conditions, and external factors. Using amplifying learning algorithms, the suspension system develops and implements an optimal energy recovery strategy during each driving cycle. This allows for a continuous increase in energy efficiency. Deep learning algorithms allow for the rapid analysis of large volumes of data and the determination of control parameters. Using evolutionary algorithms, optimal variants of the regenerative suspension system design are selected, and effective management strategies are developed based on them.

However, there are some problems and controversial aspects in the existing research. For example, the complexity of artificial intelligence algorithms, high demand for computational resources, and real-time latency can limit management efficiency in some cases. Furthermore, the relationship between the mechanical design of regenerative suspension systems and electricity storage systems, as well as their reliability and long-term operational efficiency, must be constantly analyzed. Some scientists argue that the excessive complexity of AI algorithms can increase the overall cost of a car and increase service costs. At the same time, the non-universality of control algorithms—that is, the need for individual adaptation for each vehicle model and road conditions—is also cited as a significant problem[6].

The scientific literature also extensively covers the environmental efficiency of regenerative suspension systems, the reduction of exhaust gases, and the optimization of energy consumption throughout the vehicle's service life. In some studies, it is emphasized that to reduce the overall energy consumption of a vehicle, it is necessary to integrate not only regenerative suspension systems but also other energy-saving technologies (e.g., regenerative braking systems, aerodynamic optimization, low-friction tires, etc.). This approach allows for maximizing energy efficiency and improving the overall performance characteristics of the vehicle. In particular, research is being conducted on the integration of regenerative suspension systems with other energy-saving systems in hybrid and fully electric vehicles, as well as the adapted operation of control algorithms.

The works of national and regional scientists are aimed at developing the optimal design of regenerative suspension systems, taking into account the characteristics of the road network, temperature changes, climatic conditions, and other factors, especially in the conditions of Uzbekistan. In this regard, as a result of experimental research, it has been proven that using controlled systems based on artificial intelligence can increase energy efficiency, improve vehicle comfort, and ensure

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environmental safety. At the same time, research continues on the testing of control algorithms developed by scientific teams, the implementation of results into practice, and the evaluation of their effectiveness. In particular, fundamental and applied research on the modeling, control algorithms, and energy recovery efficiency of regenerative suspension systems for hybrid vehicles is being conducted at Tashkent State Technical University, Andijan Machine-Building Institute, and other research centers.

In conclusion, the issue of increasing the energy efficiency of hybrid vehicles using regenerative suspension systems controlled by artificial intelligence is one of the most relevant and promising areas in modern automotive industry. Scientific research in this field, theoretical foundations, historical development, and practical results complement each other. As a result of the implementation of artificial intelligence algorithms, the improvement of regenerative suspension system designs, and increased control efficiency, hybrid vehicles are reaching a new level of energy efficiency, environmental safety, and driving comfort. At the same time, existing problems, critical analyses, and controversial aspects indicate the need for new scientific research in this direction in the future.

Conclusion

Based on the aforementioned scientific analyses and empirical results, it can be concluded that regenerative suspension systems controlled by artificial intelligence play a crucial role in increasing energy efficiency for hybrid vehicles. With the help of these systems, it is possible to convert the energy lost during the vehicle's movement into electrical energy and reuse it. The implementation of artificial intelligence algorithms allows for the selection of optimal control strategies in real time, increasing energy efficiency, and maintaining the vehicle's driving comfort. Research has revealed that using regenerative suspension systems controlled by artificial intelligence can reduce the total energy consumption of hybrid vehicles by up to 10-15%. At the same time, the role of these systems in environmental efficiency, reducing emissions, and optimizing energy consumption throughout the vehicle's service life is also highly valued. However, existing problems—the complexity of control algorithms, high requirements for computational resources, and the lack of universal systems—require further scientific research. In particular, taking into account national and regional conditions, it is necessary to expand research on the development of optimal designs and control algorithms for regenerative suspension systems, their practical implementation, and the evaluation of their effectiveness. In general, there are great prospects for improving the energy efficiency of hybrid cars using regenerative suspension systems controlled by artificial intelligence, and it is important to continue scientific and practical research in this direction.

References

1. Abdullaev M., Rajabov B., Kodirov N. (2021). Energy-efficient regenerative suspension systems for hybrid vehicles. Tashkent: Science and Technology Publishing House.
2. Smith J., Lee K., Müller T. (2019). Artificial Intelligence in Automotive Suspension Systems: A Review of Recent Advances. IEEE Transactions on Vehicular Technology, 68 (10), 9452–9468.
3. Sato H., Kimura Y. (2017). Regenerative suspension systems for hybrid vehicles: History, trends, and future perspectives. Journal of Automobile Engineering, 231 (6), 785–798.
4. Shodiev A., Zokirov S., Karimov I. (2022). Modeling and management of regenerative suspension systems for hybrid vehicles in the conditions of Uzbekistan. Scientific Journal of the Andijan Machine-Building Institute, 4 (1), 55-68.
5. Park J., Wang S., Chen L. (2020). Adaptive control based on machine learning for energy recovery in vehicle suspensions. Energy Conversion and Management, 214, 112889.
6. Ivanov D., Petrov A. (2018). Critical analysis of AI-driven regenerative suspension systems in hybrid vehicles. International Journal of Vehicle Design, 77 (1-2), 102–120.