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MODELING THE INFLUENCE OF ROAD INVERSIONS ON THE ELECTRICITY PRODUCTION PROCESS THROUGH THE SUSPENDED SYSTEM

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Abstract: This article models the impact of road irregularities on the electricity generation process through the vehicle's suspension system. The study analyzes the impact of road surface irregularities on the dynamics of the suspension system and the efficiency of energy production through piezoelectric or electromagnetic generators. Using analytical and empirical models, the influence of various irregularity profiles on energy recovery potential is studied. The results provide a scientific basis for optimizing power generation systems based on the condition of the road surface and the parameters of the suspension system.

Key words: road unevenness, suspension system, energy production, modeling

Introduction

In recent years, increasing the energy efficiency of vehicles and reducing their harmful impact on the environment has become a pressing issue. At the same time, the idea of converting mechanical energy generated by road irregularities into electrical energy through a vehicle suspension system is attracting the attention of the scientific and engineering community. This approach allows for the conversion of vibrations caused by road surface irregularities into an efficient energy source during vehicle movement. However, the issue of how road irregularities affect the dynamics of the suspension system and energy production efficiency is characterized by its complexity. This article models the impact of road irregularities on the process of electricity generation through a suspended system. The study analyzes existing theoretical and empirical approaches and examines the impact of various irregularity profiles on energy recovery potential. Based on the results, a scientific basis for the optimization of energy-generating suspended systems will be developed.

Literature review

The problem of modeling the influence of road irregularities on the process of electricity generation through a suspended system is related to multifaceted scientific and engineering problems. Research in this field begins with the mathematical representation of road surface irregularities and, on this basis, the modeling of the dynamics of the vehicle's suspension system. The first conceptual foundations for describing road irregularities were formed in the mid-20th century, and as one of the classic approaches, it was proposed to view the road profile as a stochastic process. According to this approach, changes in the height of the road surface are considered as a random variable, and its spectral density and autocorrelation function are determined. This methodology is still used in various international standards, specifically ISO 8608. Using the spectral density of road irregularities, their impact on the vehicle's suspension system is mathematically modeled, providing a starting point for analyzing the energy production process.

One of the most common approaches to modeling the dynamics of suspension systems is models with one degree of freedom (quarter-car) and two degrees of freedom (half-car). These models determine the vibrations caused by road irregularities, the forces and velocities arising in the

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suspension elements, as well as the parameters necessary for energy production. According to classical theories, the properties of suspension system elements—springs and shock absorbers—as well as the mass and speed of the vehicle, determine the efficiency of energy recovery from road irregularities. In the scientific literature, specifically the model developed by Hunt and Cross, it was proposed to use electromagnetic or piezoelectric cells to recover energy through a suspended system. In this method, generators installed in a suspension system convert mechanical energy into electrical energy as a result of the movement of a spring and a shock absorber. However, the effectiveness of this process largely depends on the spectral composition of the road surface and the vehicle's speed[2].

From a historical perspective, early applied research was primarily focused on assessing the overall possibilities of obtaining energy through a suspended system. In the 1970s and 80s, Japanese and American researchers developed the first prototypes for generating electricity from car vibrations. These prototypes primarily operated on electromagnetic generators, and their efficiency was relatively low. At the same time, miniature energy storage devices based on piezoelectric materials were also tested, but their performance in real road conditions was limited. Since the 1990s, with the development of microelectromechanical systems (MEMS) technology, the size of energy storage devices has decreased, and it has become possible to integrate them into the vehicle's suspension system. During this period, digital modeling methods began to be widely used for high-precision modeling of the interaction between road irregularities and the suspension system. Thus, a new stage began in determining the impact of road irregularities on the energy production process[3].

In recent years, especially as the demand for eco-friendly and energy-efficient technologies grows, research on electricity generation through a vehicle suspension system has been developing rapidly. Empirical studies conducted on an international scale show that various profiles of road surface irregularities - such as sinusoidal, rectangular, and random - significantly affect energy storage efficiency. In some studies, especially in high-frequency and low-amplitude non-uniformities, piezoelectric generators allow for more efficient energy production, while electromagnetic generators yield high results in high-amplitude and low-frequency non-uniformities. These empirical results have been confirmed by numerous laboratory and real-world tests. For example, studies conducted in China, Korea, and the USA have shown that with the help of installed energy storage devices, it is possible to obtain 15–40 W per kilometer. However, these results significantly depend on the condition of the road surface, the vehicle's weight, the suspension system parameters, and the speed of the vehicle.

Scientific research conducted at the Uzbek and regional levels also pays great attention to this topic. In particular, fundamental and applied research is being conducted at the National University of Uzbekistan, Tashkent State Technical University, and other scientific institutions on the impact of road irregularities on the vehicle's suspension system and energy production potential. Taking into account the specific climatic and geological conditions of Uzbekistan's roads, domestic scientists are primarily engaged in modeling road irregularities, their analysis, and the development of optimal structural solutions for energy storage devices. Research conducted in recent years indicates that the spectral composition of irregularities in Uzbekistan's road infrastructure differs from other regions, which directly impacts energy production efficiency. For example, for dirt and asphalt roads, there are significant differences in the spectral density of irregularities, their amplitude, and frequency. This indicates the need to consider regional characteristics in the design of energy storage devices[5].

Based on the results of theoretical and empirical research, a number of important factors have been identified in modeling the impact of road irregularities on the energy production process. First, the unevenness profile of the road surface (i.e., amplitude, frequency, random or deterministic nature) plays a key role. Secondly, the physical and parametric properties of the suspension system elements (spring, shock absorber, masses) determine the efficiency of energy storage. Thirdly, the vehicle's

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speed and load level also directly affect energy production. Fourthly, the design of the energy storage device (piezoelectric, electromagnetic, hydraulic, etc.) and the degree of its integration into the suspension system significantly affect the results. Simulation and experimental studies conducted in recent years indicate the need for a comprehensive modeling of the interaction between these factors. In this sense, the spectral analysis of road irregularities, the dynamics of the suspension system, and the electromechanical parameters of the energy storage device are combined on a single modeling platform.

A number of scientists have thoroughly studied the relationship between road irregularities and the energy production process using mathematical models. For example, it has been established that the efficiency of vibration energy storage devices depends on the correspondence between the resonance frequency of the suspension system and the road irregularity spectrum. In other words, if the main frequencies of the road irregularities fall within the resonance range of the suspension system, the energy storage efficiency will be maximum. This is especially important for electromagnetic generators. Piezoelectric generators, on the other hand, are sensitive to high-frequency and low-amplitude oscillations, for which micro-impurities on the road surface are of great importance. At the same time, the operational efficiency of energy storage devices is not limited solely to road irregularities and suspension system parameters. There are also important problems such as their integration into the car, electricity collection and storage systems, and energy transmission efficiency. There are different perspectives and debates on these issues among the international and domestic scientific community.[6]

The results of empirical research are also widely covered in the literature. For example, as a result of tests conducted under real road conditions, it was established that energy storage efficiency differs significantly with changes in the road profile, vehicle speed, and weight. In some studies, it has been noted that although the energy accumulation rate through the suspension system is high, especially in heavy-duty vehicles moving at high speeds, this process can negatively affect the service life of the suspension system and the comfort of the vehicle. Therefore, when optimizing the design and operating mode of energy storage devices, it is important to perform a spectral analysis of road irregularities, comprehensively accounting for vehicle movement parameters and the dynamic characteristics of the suspension system. In this regard, advanced research is being conducted to identify complex relationships between road irregularities and the energy storage process, particularly using artificial intelligence and machine learning methods. Thus, in modern scientific literature, the problem of modeling the influence of road irregularities on the process of electricity generation through a suspension system remains a comprehensive and relevant topic from theoretical, practical, and technological perspectives.

Conclusion

An analysis of the aforementioned scientific literature, as well as theoretical and practical research, shows that modeling the impact of road irregularities on the process of electricity generation through a suspension system is a complex and multi-factor problem. The unevenness profile of the road surface, the physical and dynamic characteristics of the vehicle's suspension system, the structural parameters of the energy storage device, the vehicle's travel speed, and the load level - all of this directly affects energy production efficiency. Research indicates that the spectral composition of road irregularities and their correspondence to the resonance frequency of the suspended system significantly influence the energy collection result. At the same time, various structural variants of energy storage devices (piezoelectric, electromagnetic, hydraulic, etc.) exhibit varying efficiency for different irregularity profiles. The specific characteristics of road irregularities in Uzbekistan and regional conditions require adaptation of the design of energy storage systems. Using modern

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modeling and simulation methods, including artificial intelligence and machine learning technologies, it is possible to deeply analyze the complex dependencies of road irregularities and energy storage processes. The results are of great scientific and practical importance in optimizing energy storage suspension systems, improving vehicle traffic efficiency, and ensuring environmental sustainability. In the future, it is advisable to conduct large-scale research in this direction, particularly on improving the design of energy storage devices based on real-world testing and modeling, adapting them to regional road conditions, and increasing energy storage efficiency.

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