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An overview of drive's seat suspension systems of vehicles

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ABSTRACT: *The driver's seat suspension system plays a crucial role in isolating vibrations caused by road surface irregularities, significantly impacting driver comfort and safety. This paper provides a comprehensive overview of vehicle dynamic models that incorporate seat suspension systems, highlighting the importance of effective vibration isolation. It discusses both active and semi-active seat suspension systems, which have shown considerable promise in enhancing ride comfort. Recent research findings reveal that both active and semi-active seat suspensions can markedly improve comfort levels, especially under varying driving conditions. This review examines the effectiveness of different suspension types and identifies emerging trends in seat suspension design, including advanced control strategies and optimization techniques. These findings contribute valuable insights for developing advanced seat suspension systems in modern vehicles, ensuring enhanced comfort and safety for drivers.*

KEYWORDS: *seat suspension system, dynamic model, ride comfort, semi-active seat suspension*

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I. INTRODUCTION

Vehicles play an essential role in daily transportation, enabling the movement of goods and people efficiently across various terrains and distances. As global standards of comfort and safety rise, the demand for high-quality vehicles that offer smooth and reliable operation has intensified. One of the primary challenges in achieving these standards is the mitigation of vibrations that occur due to irregular road surfaces, affecting both the vehicle's overall performance and the health of its occupants. These vibrations, when transmitted to the driver, not only reduce the driver's control and comfort but, over time, can lead to significant health issues, particularly during prolonged exposure. According to ISO 2631-1, the international standard on human response to whole-body vibration, indicated that long-term exposure to certain vibration levels can cause health disorders, especially involving the spine and other musculoskeletal structures [1, 2]. The need for effective vibration isolation systems in vehicles has, therefore, become a priority, with the seat suspension system emerging as a key solution in reducing the transmission of road-induced shocks and vibrations to the driver. Traditional vehicle suspension systems have long been tasked with isolating the vehicle body from road disturbances, improving both ride comfort and safety [3, 4, 5]. However, conventional suspension systems face limitations in adapting to varying and unpredictable road conditions, as their passive components cannot adjust in real time [6, 7]. This rigidity in passive suspensions hinders the ability to fully absorb shocks across a range of driving environments. To overcome these limitations, active and semi-active suspension systems have been introduced, offering more responsive solutions to vibration isolation [8, 9, 10,]. Active suspensions, utilizing sensors, actuators, and real-time control algorithms, can dynamically adjust suspension parameters, such as damping and stiffness, to counteract road disturbances and optimize comfort. Similarly, semi-active suspension systems, although simpler than fully active systems, can adapt to changing road conditions by varying damping characteristics, which provides substantial improvements in vibration isolation. These advancements have made active and semi-active suspensions attractive options for enhancing the safety and comfort of vehicle occupants, allowing suspensions to adjust to changing road conditions in real time. However, active and semi-active suspension systems also come with challenges, including higher costs, greater complexity, and increased maintenance requirements. Moreover, the issue of controlling vibration in vehicles is inherently complex, as dynamic models involve multiple inputs and outputs, with various objectives such as comfort, safety, and handling that often conflict. Given these complexities, seat suspension systems present a viable solution by targeting vibrations at their source the driver's seat and directly addressing the primary causes of discomfort and health risks for drivers. Consequently, researchers have shifted focus to seat suspension systems as an alternative means to achieve effective vibration isolation. Seat suspension systems studied across a wide range of vehicle types, including a passenger vehicle [11, 12], buses [13], trucks [14], and agricultural machinery [15]. The differing nature of these vehicles and their operating environments requires tailored solutions for each application. For example, agricultural machinery frequently operates on uneven and rough terrain, where vibration levels are significantly higher than those encountered by typical road vehicles. In such cases, an effective seat suspension system is crucial not only for comfort but also for occupational health. In buses and trucks, where drivers spend extended hours on the road, seat suspension systems also play a vital role in ensuring long-term well-being and maintaining driver alertness. Research has increasingly focused on developing seat suspension systems that offer enhanced adaptability and vibration isolation performance through both semi-active and active configurations. Consequently, active seat suspension systems and semi-active seat suspension systems have been proposed [16, 17, 18].

This paper provides a thorough review of drive seat suspension systems, examining both passive and advanced active and semi-active seat systems, as well as the control strategies employed to maximize their effectiveness. By exploring the role of drive seat suspensions across various vehicle types and dynamic models, the paper aims to shed light on the significance of these systems in enhancing vehicle comfort and safety. Furthermore, it identifies the challenges and limitations of current systems, offering insights into the latest trends and future directions in seat suspension technology. This research contributes to the growing body of knowledge on vibration isolation in vehicles, underscoring the potential of seat suspension systems to improve driver comfort, health, and overall driving experience.

II. SEAT SUSPENSION SYSTEM

Passive seat suspension: The passive seat suspension system consists of springs and dampers, providing a simple structure that serves to isolate vibrations from the vehicle floor or cabin, protecting the driver from unwanted motions. This type of system is widely used in vehicles due to its simplicity and cost-effectiveness, but its limitations arise in its ability to adapt to varying road conditions and driving scenarios. Various studies have been conducted to explore and optimize seat suspension systems for different vehicle types, with numerous dynamic models being developed to evaluate their performance.

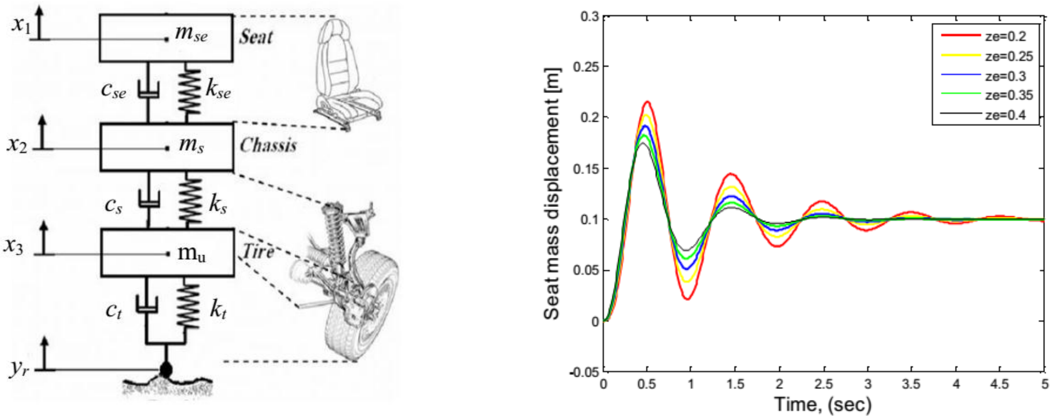


Figure 1: Dynamic model and simulation results [11]

In [11], a three-degree-of-freedom (DOF) dynamic model was established to analyze the behavior of the seat suspension system. This model, as shown in Figure 1, was designed to simulate the interaction between the seat and the vehicle body, accounting for factors such as road disturbances and seat position. The results from this model allowed researchers to identify key parameters that influence vibration isolation performance and provided insights into improving the design of passive seat suspension systems.

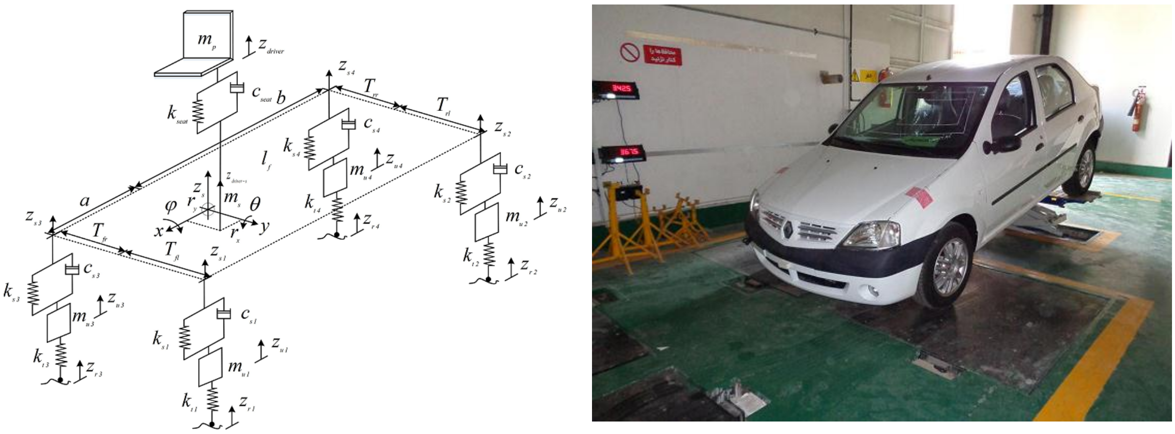


Figure 2. Dynamic Modeling and Experiments [12]

In another study, a full vehicle dynamic model was proposed to simulate the effects of random road disturbances on the seat suspension system [12], as shown in Figure 2. The model was particularly useful for studying the system's response to different road conditions, such as uneven surfaces and potholes. Based on this model, optimization of the seat suspension system's parameters was carried out to enhance its performance in isolating vibrations from the road. The study found that adjusting parameters like damping and stiffness could significantly improve the ride comfort

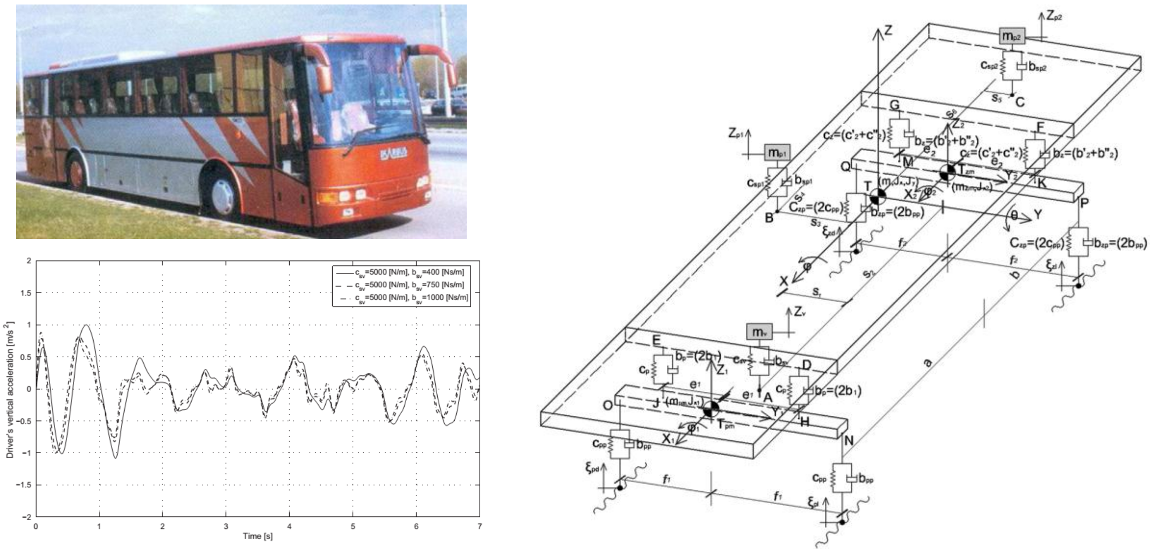


Figure 3. Bus Dynamics Model [13]

Furthermore, in [12], a dynamic model for a bus was developed that considered various seating positions within the vehicle, as shown in Figure 3. This model allowed for a more comprehensive study of the effects of different seat locations on vibration isolation and comfort. It revealed that the performance of the seat suspension system varies depending on the seating position, highlighting the importance of tailoring the system to specific vehicle types and use cases. The findings emphasized the need for flexible design solutions to ensure that passengers experience optimal comfort and reduced vibrations, regardless of their seating position.

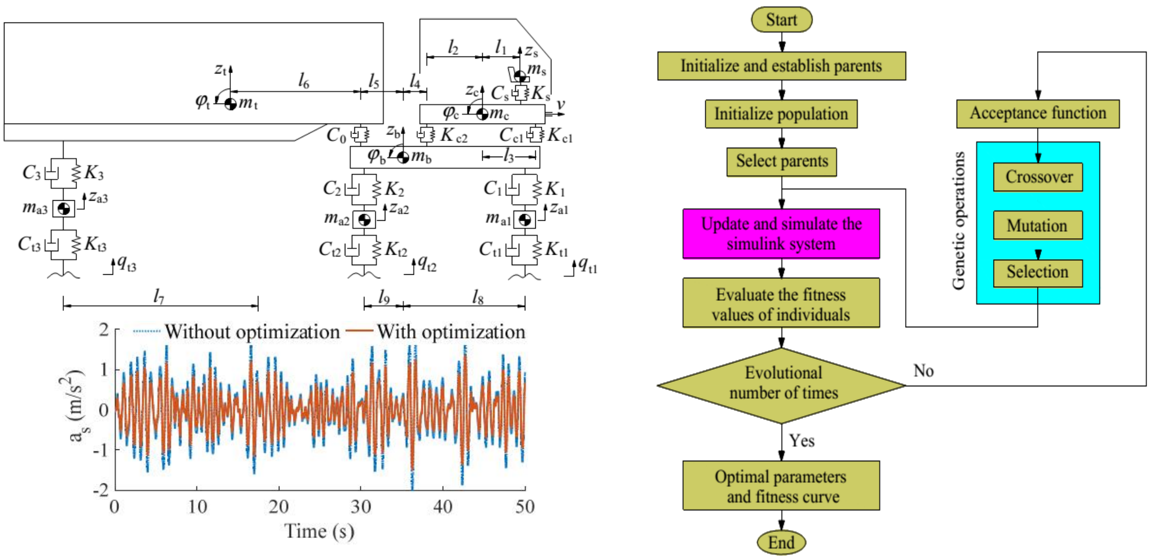


Figure 4. Optimized seat suspension design [14]

In [13], a dynamic model for a truck was proposed, with the seat suspension system being optimized using a genetic algorithm (GA), as shown in Figure 4. The study focused on optimizing the parameters of the seat suspension system to enhance comfort for truck drivers, who often spend long hours on the road. By applying the GA, the optimization process efficiently identified the best combination of damping and spring characteristics, resulting in a significant reduction in vibration transmissibility and improved ride quality.

Semi-active seat suspension: The primary goal of implementing semi-active seat suspension systems is to reduce vibration transmissibility at low frequencies while maintaining high performance at higher frequencies. Semi-active systems are particularly advantageous due to their lower power requirements compared to fully active control systems. Their adjustable damping and stiffness characteristics have led to their widespread application across various industries for vibration control. With advancements in magnetorheological (MR) and electrorheological (ER) dampers, semi-active seat suspensions have been developed to offer variable damping forces while consuming less power than active systems. In [19], a semi-active seat suspension system utilizing an MR damper was proposed, with the Skyhook control strategy selected to adjust the damper's damping coefficient, as illustrated in Figure 5. The results showed that the semi-active seat suspension system provides superior vibration isolation compared to conventional seat suspension systems.

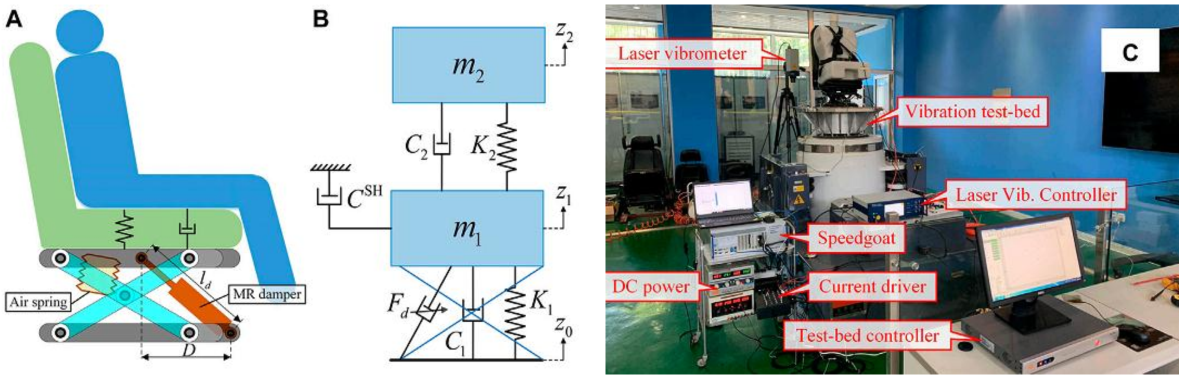


Figure 5. Semi-Active Seat Suspension With Magneto-Rheological Damper [19]

Active seat suspension: Active seat suspension systems can use external power to drive the system, reducing unwanted vibrations through continuous control. The advantage is that they are more robust and typically offer better performance than conventional seat suspension systems. Numerous studies have been conducted to enhance passenger comfort during travel. Active seat suspension systems can generate force using electric or hydraulic actuators according to the system's state, as shown in Figure 6. Consequently, an external power source is required, making active seat suspension systems larger, more energy-consuming, and more expensive than both passive and semi-active seat suspension control systems.

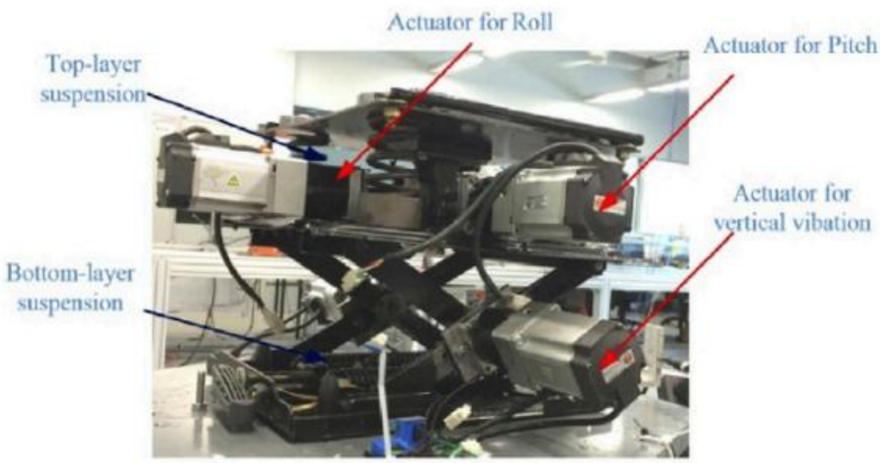
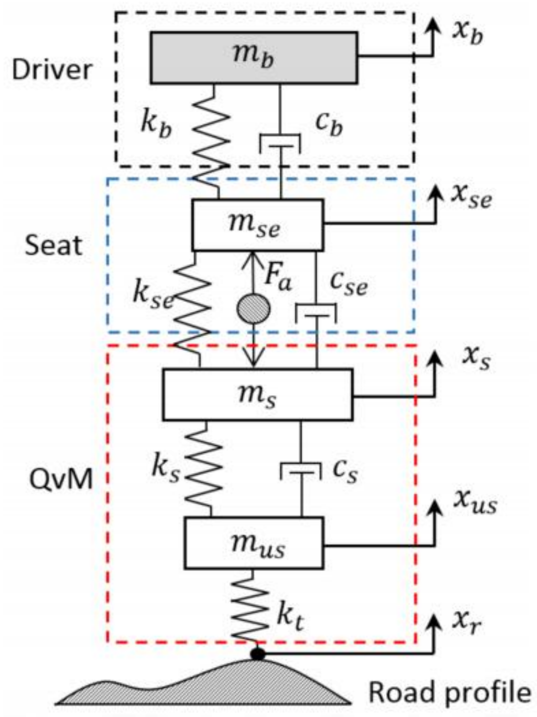


Figure 6. Structure of active seat suspension system [20]

With the advancements in science and technology today, sensor technology has become more affordable, leading to a reduction in costs. As a result, seat suspension systems continue to attract significant research attention. In [21], a PID controller was proposed for an active seat suspension system, as shown in Figure 7. The results demonstrated a substantial improvement in ride comfort compared to conventional seat suspension systems.



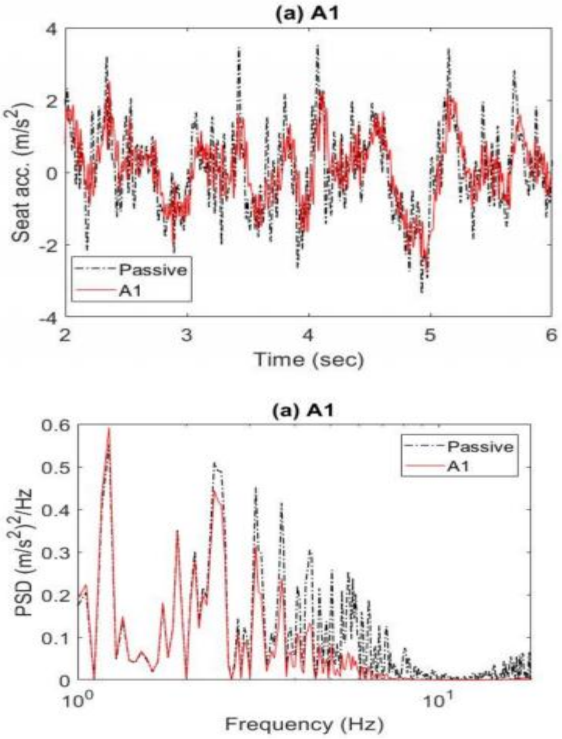


Figure 7. Dynamic model and simulation results [21]

II. CONCLUSIONS

This paper provides a comprehensive overview of drive seat suspension systems in vehicles, exploring various dynamic models that contribute to enhancing ride comfort and reducing vibrations. The main conclusions drawn from the analysis are as follows: (i) The paper presents a range of dynamic models developed for different vehicle types, highlighting how each model caters to the specific requirements of the suspension system in terms of vibration isolation. These models include three-degree-of-freedom (DOF) systems, full vehicle dynamic models, and vehicle-specific models for buses, trucks, and other vehicles. Each model demonstrates the importance of tailoring seat suspension designs to the vehicle's characteristics and operational environment. (ii) A key finding is the optimization of seat suspension parameters such as damping and stiffness. Studies show that adjusting these parameters significantly improves vibration isolation and ride comfort, especially in vehicles subject to random road disturbances. The optimization of seat suspension systems can lead to a notable reduction in vibration transmissibility, ensuring better protection for the driver and passengers in various driving conditions. (iii) The research also emphasizes the importance of adapting seat suspension systems for different vehicle types, including agricultural machinery, buses, and trucks. Different vehicles face distinct challenges related to road surfaces, load conditions, and driver usage. Therefore, seat suspension systems must be designed with flexibility in mind, utilizing both passive and semi-active solutions to provide optimal performance.

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