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An Overview of Strategy for Optimizing Design Parameters of Electric Vehicle Suspension Systems

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ABSTRACT:*With the automotive industry transitioning towards electric vehicles (EVs), optimizing suspension system design has become essential for enhancing ride comfort, safety, and energy efficiency. This paper provides an overview of key strategies and methodologies for optimizing the design parameters of EV suspension systems. Through establishing dynamic models and applying optimization algorithms, design parameters are refined to improve suspension performance.The reviewed studies demonstrate that optimized suspension parameters contribute to significant gains in ride comfort, vehicle safety, and road-friendliness, which are critical factors for modern EVs. The findings underscore the need for continued research in developing advanced control and optimization techniques to further enhance EV.*

KEYWORDS: *Optimizing design parameters, suspension system, electric vehicle, ride comfort*

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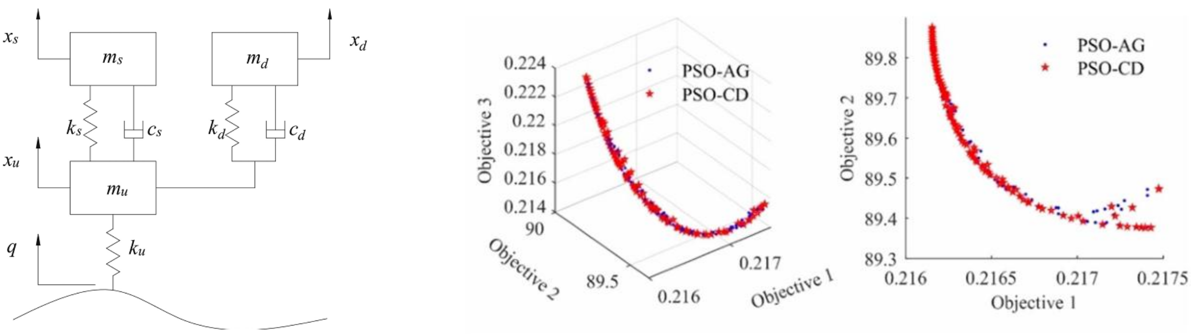
I. INTRODUCTION

As the global automotive industry undergoes a transformative shift towards electric vehicles (EVs), the demand for advancements in EV technology has become more pronounced. Driven by factors such as environmental regulations, energy conservation, and technological innovation, EVs are increasingly seen as a sustainable solution to the challenges posed by conventional internal combustion engine vehicles [1, 2, 3]. However, this transition has introduced unique engineering challenges, particularly in vehicle dynamics and suspension design. One of the unique characteristics of EVs is the increased level of vibration resulting from design differences compared to conventional vehicles. The replacement of the internal combustion engine with an electric motor and battery pack has negatively affected ride comfort in EVs [4, 5]. In particular, in-wheel motor electric vehicles (IWMEVs) present specific challenges for suspension system design. Integrating the motor directly into the wheel has significantly increased unsprung mass, which negatively impacts ride comfort [6, 7, 8, 9, 10]. As a result, the suspension system has become a critical area of focus for automotive researchers and engineers. Conventional passive suspension systems may struggle to maintain comfort and handling under varying road conditions [11, 12, 13]. To address these issues, various control strategies have been proposed to enhance suspension performance, especially for EV applications, including skyhook control [14, 15], fuzzy logic control [16], proportional-integral-derivative (PID) control [17], and linear-quadratic regulator (LQR) control [18]. Skyhook control, widely used in semi-active suspensions, attempts to emulate an idealised suspension by creating a virtual "hook" in the sky that minimizes body movement relative to the ground. This approach has proven effective in improving ride comfort; however, its performance is limited under highly dynamic load conditions, such as those experienced in IWMEVs. Fuzzy logic control, on the other hand, is a more flexible approach that can handle the uncertainties and nonlinearities associated with real-world driving. By simulating human-like decision-making, fuzzy control allows for more adaptive suspension responses. Nevertheless, it requires extensive tuning and lacks the precision of other control methods, which can make implementation challenging. PID control, a staple in many control systems, is known for its simplicity and effectiveness in various engineering applications. It adjusts the suspension response based on proportional, integral, and derivative components of the system's error signal, providing a well-rounded approach to control. However, PID control is typically less effective in handling the rapid dynamic changes in EV suspensions, particularly under variable load conditions. These drawbacks highlight the need for alternative approaches that can dynamically adapt suspension performance in response to the unique challenges posed by EVs. A promising solution to address these limitations involves optimizing suspension parameters using advanced optimization algorithms. Unlike conventional control methods, which often rely on fixed parameters, optimization algorithms allow the suspension system's design parameters to be adjusted dynamically, ensuring optimal performance under varying conditions. Optimization approaches offer a structured methodology to identify the best set of suspension parameters, balancing multiple objectives such as ride comfort, handling stability, and energy efficiency. By applying these techniques, suspension parameters can be fine-tuned to achieve a high level of performance that adapts to the dynamic requirements of EVs. Many optimization algorithms have been explored for suspension system design, including the Genetic Algorithm (GA) [19, 20], Particle Swarm Optimization (PSO) [21, 22], the Firefly Algorithm [23], NSGA-II [24], and the Artificial Fish Swarm Algorithm [25]. This paper aims to provide a comprehensive overview of strategies and methods used to optimize design parameters for EV suspension systems, focusing on identifying effective approaches to enhance ride comfort, handling stability, and overall vehicle safety. Through this exploration, the paper highlights the potential of optimized suspension systems to advance EV technology, paving the way for more efficient, comfortable, and safer electric vehicles in the future.

II. OPTIMIZATION OF SUSPENSION SYSTEM PARAMETERS

The design optimization of suspension systems for electric vehicles (EVs) has garnered considerable attention in recent scientific literature, especially given the evolving requirements for both comfort and performance in EV dynamics. According to studies published in reputable journals, suspension parameter optimization for EVs can be divided into two main approaches: one focused on in-wheel motor electric vehicles (IWMEVs), which use distributed drive systems with motors embedded directly in the wheels, and the other on central drive EVs. Each approach addresses unique challenges and leverages various optimization algorithms to enhance the suspension system's performance. The specific studies reviewed below illustrate these strategies.

For distributed drive electric vehicles: Distributed drive EVs, particularly IWMEVs, represent an innovative configuration in which motors are placed inside the wheels. This setup offers several advantages, such as improved space utilization and independent wheel control, which can enhance vehicle handling. However, the increased unsprung mass from the motor's placement within the wheel significantly impacts ride comfort and handling stability, drawing substantial attention from researchers aiming to mitigate these effects. One notable study [26] explored the dynamics of an IWMEV suspension system by developing a quarter-car model, as illustrated in Figure 1(a). Interestingly, this model incorporates a suspension system for the in-wheel motor, known as a Dynamic Vibration Absorber (DVA), to dampen the additional vibrations caused by the unsprung motor mass. The study employs a multi-objective particle swarm optimization (MOPSO) algorithm to fine-tune the suspension and DVA parameters.



(a) (b)

Figure 1: Model and optimization results [26]

The primary objectives include minimizing the root mean square (RMS) values of body acceleration, suspension working space, and dynamic tire load. As shown in Figure 1(b), the Pareto front illustrates the trade-offs between these objectives. The optimized suspension system reduces RMS body acceleration, suspension working space, and dynamic tire load compared to the original suspension system, demonstrating significant enhancements in ride comfort, safety, and road holding for IWMEVs

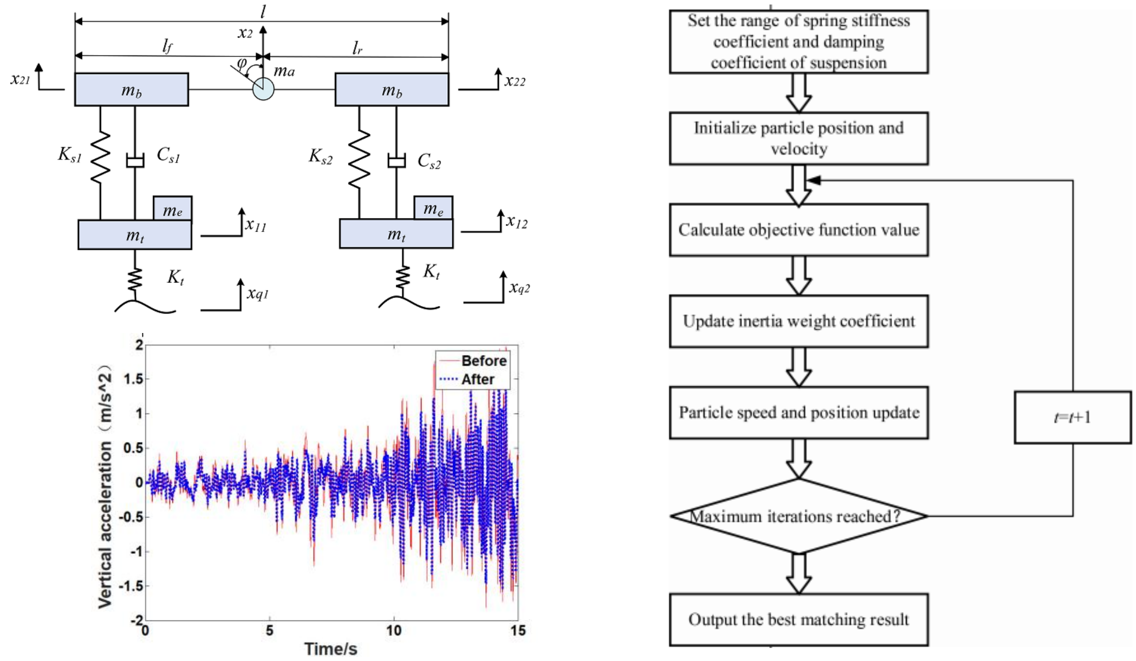


Figure 2: Some illustrative results [27]

Similarly, another study [27] builted upon this approach by developing a half-car dynamic model that considers the motor's mass, as depicted in Figure 2. Adaptive Particle Swarm Optimization (APSO) is used to optimize the suspension system for various objective functions, including the RMS values of vertical acceleration and pitch body acceleration under random road profiles of classes B and C at a speed of 20 m/s. The simulation results reveal that the optimized suspension system achieves reductions of 20.2% and 18.4% in vertical acceleration and pitch acceleration, respectively, compared to the original suspension setup. These findings indicate that the optimized suspension parameters effectively enhance both ride comfort and vehicle stability.

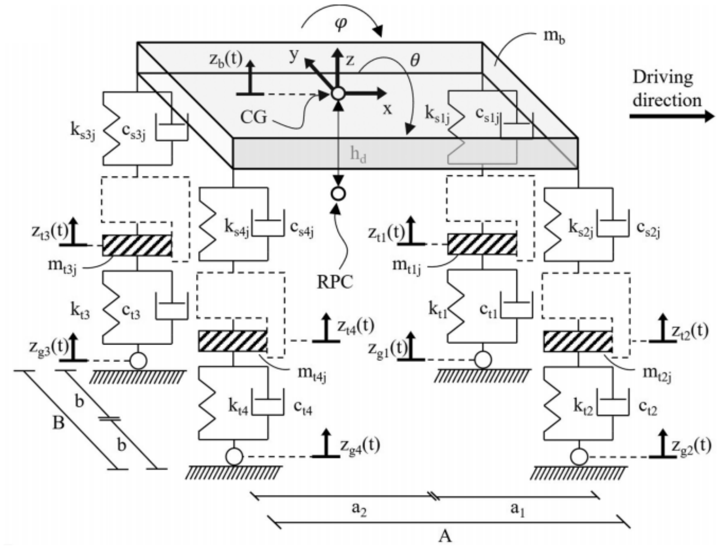


Figure 3: A dynamic full model for IWMEVs [28]

Furthermore, a dynamic full model for IWMEVs is proposed in [28], as shown in Figure 3. This study employs a Genetic Algorithm (GA) to optimize the suspension parameters under an E-class random road profile at speeds ranging from 5 m/s to 40 m/s. Additionally, a fishhook maneuver test is performed to evaluate the suspension’s impact on lateral stability. The results confirm that the GA-optimized suspension system significantly improves ride comfort and safety, especially in lateral stability, which is critical for IWMEVs given their unique dynamics.

*For centralized drive electric vehicles:*For centralized drive EVs, the suspension optimization problem is somewhat less complex due to their similarity to traditional vehicles with a central motor configuration. Despite this, centralized drive EVs still benefit from parameter optimization to improve ride comfort and handling. A representative study [5] develops a dynamic model that includes the driver's seat, as shown in Figure 4. This model allows for more realistic simulations of ride comfort by considering seat dynamics.

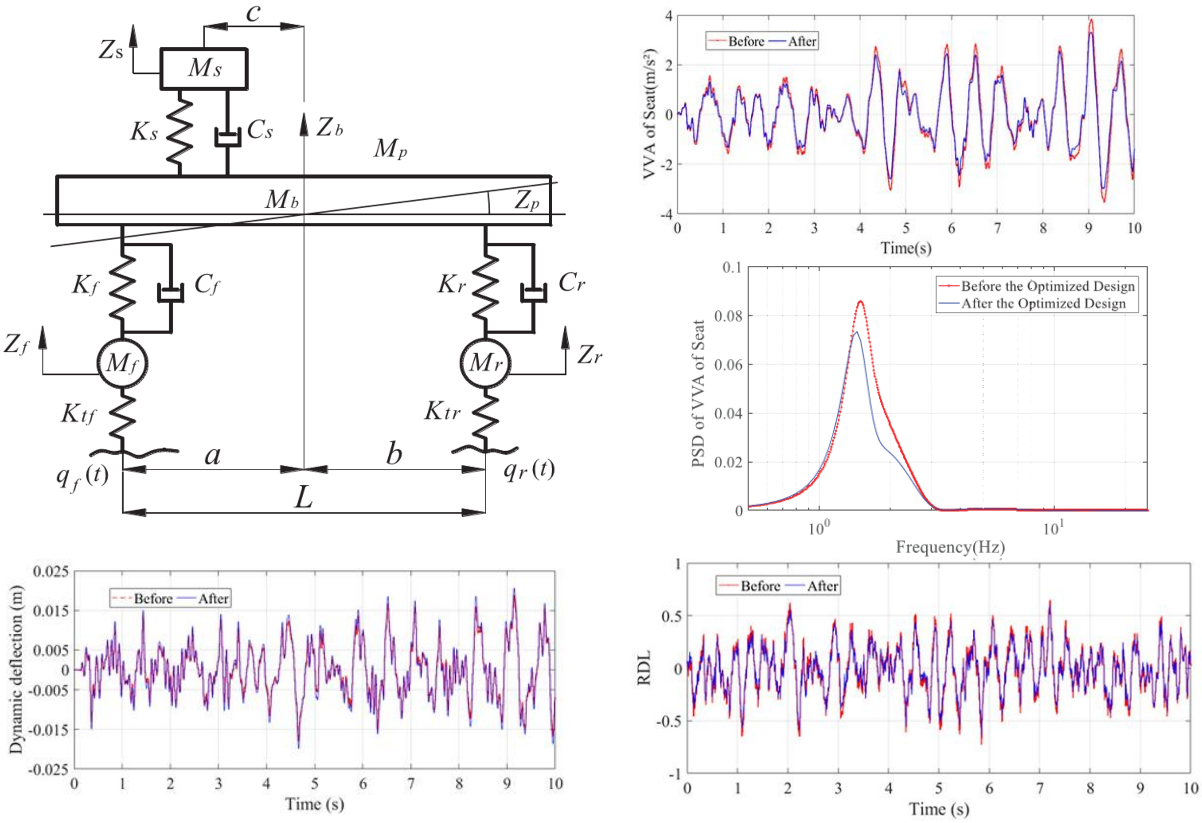


Figure 4: Model and optimization results [29]

In this study, the GA tool in MATLAB is used to optimize the suspension parameters. The objective functions include the RMS values of seat acceleration, dynamic deflection of the rear suspension, and relative dynamic load of the rear suspension, evaluated on a C-level road input at a speed of 30 km/h. The results indicate that the optimized suspension system provides notable improvements in these objective functions, enhancing both comfort and performance relative to the original suspension system.

III. CONCLUSIONS

This paper provides a comprehensive overview of optimization strategies for electric vehicle (EV) suspension systems, along with a discussion of recent findings. Several conclusions can be drawn from the analysis: (i) By optimizing suspension parameters, EVs have achieved significant improvements in ride comfort, safety, and handling. (ii) Although a variety of optimization algorithms are available, the application of these methods specifically for EV suspension systems remains limited. This presents valuable research opportunities for scholars to explore advanced optimization techniques tailored to the unique dynamics of EVs.

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