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Manufacturer Demand and Engineering Adaptation: An Interdisciplinary Study of Suspension System Design and Tuning for Motorcycles and Electric Two-Wheelers

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Abstract

This study investigates the design and tuning of suspension systems for motorcycles, mopeds, and electric two-wheelers from the perspective of manufacturer-driven demand. Rather than focusing solely on technical specifications, the research adopts a practice-oriented and interdisciplinary approach to analyze how engineering decisions are shaped by differentiated product positioning, user expectations, and industrial constraints. Drawing on real-world R&D scenarios, the paper examines the interaction between suspension system parameters and overall vehicle performance, including comfort, handling stability, durability, and cost efficiency. It further systematizes the design logic of key parameters such as load capacity, suspension stroke, stiffness, and structural configuration, and analyzes the iterative tuning process based on real-vehicle testing and feedback mechanisms. Through this process, a demand-driven adjustment framework is established, in which parameter optimization is continuously refined through empirical verification and scenario-based evaluation. The findings indicate that effective suspension system development depends on the coordinated integration of design principles, tuning strategies, and system-level matching with vehicle architecture. Moreover, the study highlights that engineering practices in this field are not purely technical, but are embedded within a broader socio-technical context involving manufacturer requirements, cost constraints, and user-oriented performance expectations. By bridging practical engineering experience with analytical abstraction, this research provides a structured reference for suspension system development and contributes to interdisciplinary discussions on how demand-driven design influences technological implementation in the two-wheeler industry.

Keywords: Suspension System; Motorcycles; Tuning Methodology; Industrial Practice; System Integration

1. Introduction

Motorcycles, mopeds and electric two-wheelers have become essential modes of transportation for both urban and rural mobility in China, playing a significant role in daily commuting, short-distance logistics and flexible travel (Xie et al., 2025; Scorrano & Danielis, 2025). With the continuous expansion of application scenarios and user groups, the development of such vehicles is no longer limited to basic functional requirements such as power output and endurance, but increasingly emphasizes driving safety, riding comfort and overall user experience. In this context, the suspension system, as the key interface between the vehicle and road surface, has emerged as a critical subsystem that directly influences vibration attenuation, body stability and tire-road interaction.

From an engineering perspective, the performance of the suspension system determines the vehicle's ability to respond to complex and variable road conditions. Insufficient suspension performance may lead to excessive vibration transmission, unstable body posture and reduced tire adhesion, thereby affecting braking performance, cornering stability and overall operational safety (Ferhath & Kasi, 2024; Zang et al., 2025). At the same time, from an industrial perspective, suspension design has become an important factor in product differentiation and market competitiveness, as manufacturers seek to meet increasingly diversified user expectations under constraints of cost, weight and durability.

At present, the demands of main engine manufacturers for suspension systems exhibit clear differentiation across vehicle categories. Fuel motorcycles, particularly high-performance and large-displacement models, emphasize handling precision, high-speed stability and durability under extreme operating conditions. Mopeds, which are primarily used for urban commuting, prioritize cost efficiency, structural simplicity and ease of maintenance, while still maintaining acceptable levels of comfort (Rui & Othengrafen, 2025). In contrast, electric two-wheelers place greater emphasis on fine vibration filtering, riding comfort and energy efficiency, with particular attention to the influence of suspension weight and damping characteristics on vehicle endurance.

Despite these differences, suspension system development is increasingly characterized by a demand-driven engineering paradigm, in which design decisions are shaped by the integration of vehicle positioning, user behavior and industrial constraints. Based on this context, this paper analyzes the key design principles and tuning methodologies of suspension systems from the perspective of manufacturer requirements. By synthesizing practical R&D experience and general engineering logic, the study aims to establish a structured understanding of how demand-oriented design and iterative tuning processes contribute to the optimization of suspension performance in real-world applications.

2. Core Demands of Main Engine Manufacturers for Suspension Systems

2.1. Demand Differences Across Vehicle Categories

The design direction of suspension systems is fundamentally determined by the differentiated requirements of main engine manufacturers, which are closely linked to vehicle type, usage scenario and target user group (Llopis-Albert et al., 2023; Ferhath & Kasi, 2024). For motorcycles, especially large-displacement sport models, suspension systems are required to achieve a high level of dynamic performance, balancing stability during high-speed operation with responsiveness in cornering conditions. In such cases, suspension design must effectively control body roll, suppress vibration under uneven road excitation and ensure precise tire-ground contact, thereby supporting advanced handling performance.

In contrast, mopeds are typically characterized by compact structure and lower operating speeds, leading manufacturers to prioritize cost control, structural simplicity and ease of installation. The suspension system in this context is expected to provide sufficient shock absorption for daily commuting while maintaining low production and maintenance costs. Electric two-wheelers, driven by the rapid expansion of urban mobility and delivery services, exhibit a different set of priorities. Users of these vehicles place greater emphasis on comfort during prolonged use, requiring the suspension system to effectively filter high-frequency road vibrations and enhance riding smoothness. At the same time, the influence of suspension weight on energy consumption and driving range introduces additional design constraints, making lightweight and efficiency-oriented solutions particularly important.

2.2. Common Demand Characteristics and Engineering Implications

Despite the diversity of application scenarios, main engine manufacturers share several fundamental requirements for suspension systems, which collectively define the baseline for engineering design. Durability is the primary concern, as suspension components are subjected to continuous cyclic loading and complex road conditions over extended periods. Manufacturers therefore require that suspension systems maintain stable performance throughout the product lifecycle, with service life aligned with warranty expectations and minimal risk of failure under typical usage conditions.

Adaptability represents another critical requirement, referring to the ability of the suspension system to achieve effective integration with the overall vehicle architecture (Ferhath & Kasi, 2024; Qiu et al., 2025). This includes compatibility with frame structure, coordination with power system vibration characteristics and alignment with tire performance. Poor system integration may lead to issues such as structural interference, inefficient vibration attenuation or mismatched dynamic response, ultimately affecting vehicle stability and user experience.

In addition, adjustability has become an increasingly important consideration in modern suspension design. Some manufacturers expect suspension systems to provide basic adjustment capabilities, such as preload and damping regulation, allowing performance to be fine-tuned according to different user preferences and operating conditions. This trend reflects a shift toward more flexible and user-oriented design strategies, in which suspension systems are not only required to meet standardized performance criteria but also to accommodate variability in real-world usage.

Taken together, these common requirements illustrate that suspension system design is not merely a technical task, but a process of balancing multiple constraints within a broader socio-technical context. Engineering decisions must simultaneously address performance, reliability, cost efficiency and user adaptability, highlighting the importance of demand-driven design frameworks in contemporary vehicle development.

3. Design Principles of Suspension Systems

3.1. Basic Parameter Design

The design of suspension systems begins with the definition of core parameters, which are fundamentally derived from the overall vehicle design requirements specified by main engine manufacturers (Trzesniowski, 2023). Among these parameters, load matching represents the primary constraint, as the suspension must be capable of supporting both the curb weight and maximum load of the vehicle under varying operating conditions. For instance, the rear suspension of electric two-wheelers is typically designed to accommodate a load range of 50–80 kg, while mopeds require a broader load adaptation range due to more variable usage scenarios. These load parameters directly influence the selection of structural dimensions and stiffness characteristics, forming the basis of suspension performance.

In addition to load considerations, suspension stroke and stiffness must be carefully configured in accordance with vehicle positioning and road conditions (Kulkarni et al., 2024). Shorter suspension strokes, commonly applied in sport motorcycles, enhance responsiveness and handling precision, whereas longer strokes, often used in electric two-wheelers, improve comfort by increasing the capacity for vibration absorption. Stiffness selection further determines the dynamic response of the suspension system: excessive stiffness reduces comfort and increases vibration transmission, while insufficient stiffness may lead to instability, excessive body roll and bottoming. Therefore, parameter design should be understood as a constrained optimization process in which performance, safety and user experience are balanced within a demand-driven engineering framework.

3.2. Structural and Material Selection

Structural configuration and material selection play a decisive role in determining both the functional performance and economic feasibility of suspension systems (Borase et al., 2024). Designers must balance performance requirements with cost constraints imposed by main engine manufacturers, leading to differentiated structural choices across vehicle categories. Telescopic front suspension systems are widely adopted due to their structural simplicity, reliability and ease of installation, making them suitable for mopeds and electric two-wheelers. In contrast, rear suspension systems exhibit greater diversity, with high-performance motorcycles often employing multi-link or more complex configurations to enhance dynamic control, while cost-sensitive models rely on simplified single-tube or double-tube designs.

Material selection further reflects the trade-off between durability and lightweight design. High-strength steel is typically used for key load-bearing components to ensure structural integrity and fatigue resistance under long-term cyclic loading. Meanwhile, aluminum alloys and other lightweight materials are increasingly adopted in non-critical or semi-structural components to reduce overall vehicle weight, which is particularly important for electric two-wheelers where energy efficiency and range are directly affected by mass. All material choices must comply with relevant technical standards to ensure reliability and safety. In this sense, structural and material design is not only a technical decision but also an industrial optimization process shaped by performance targets, cost considerations and regulatory requirements.

3.3. Matching Design with Vehicle Overall Systems

The suspension system cannot be treated as an isolated component, as its performance is inherently dependent on its interaction with the overall vehicle system (Wang et al., 2024). Effective design therefore requires a system-level matching approach, in which the suspension is coordinated with the frame structure, power system and tire characteristics. From the perspective of frame integration, installation dimensions must precisely match the interface design to avoid assembly deviations that could compromise stability and durability. Even minor discrepancies in mounting geometry may lead to uneven load distribution or abnormal stress concentrations.

Furthermore, the interaction between suspension dynamics and power system behavior must be carefully considered. In fuel motorcycles, the vibration characteristics of the engine influence the required damping response, necessitating a tuning strategy that minimizes vibration transmission while maintaining control stability. In electric two-wheelers, the torque output characteristics of the motor may affect suspension compression behavior, particularly under acceleration conditions. Tire characteristics also play a critical role, as the grip performance determines how suspension damping should be adjusted to balance comfort and handling. This multi-system coordination reflects a broader system integration principle, in which suspension design becomes a key node within a complex socio-technical system involving mechanical performance, user behavior and environmental conditions.

4. Tuning Processes and Methods of Suspension Systems

4.1. Preparations

The tuning process of suspension systems begins with systematic preparation, which establishes the foundation for subsequent adjustments. This stage involves the comprehensive collection of vehicle-level data provided by main engine manufacturers, including parameters such as vehicle mass, center of gravity distribution, tire specifications and intended operating conditions. These data define the initial boundary conditions for tuning and ensure that parameter adjustments are aligned with actual application scenarios.

Based on this information, initial parameter settings are determined, including preload and damping values. These initial configurations are not arbitrary but are derived from both engineering experience and vehicle positioning. For example, electric two-wheelers typically adopt moderate preload settings to prioritize comfort in daily use, while sport motorcycles require higher preload values to ensure stability during high-speed operation. This preparation phase reflects the transition from theoretical design to practical implementation, where standardized design logic is translated into initial tuning configurations.

4.2. Steps of Real Vehicle Tuning

Real vehicle tuning represents the core phase of suspension development, characterized by an iterative process combining empirical testing and parameter optimization. The process begins with road testing under representative conditions specified by main engine manufacturers, including smooth, rough and irregular road surfaces. During these tests, key performance indicators such as vibration transmission, body roll behavior and rider perception of comfort are systematically recorded.

Based on the feedback obtained, targeted parameter adjustments are carried out. For example, excessive stiffness can be mitigated by reducing damping forces, while insufficient stability may require increased stiffness or preload. Issues such as rapid rebound and oscillation are addressed by adjusting rebound damping characteristics. Each adjustment is followed by repeated testing to verify its effectiveness, forming a continuous feedback loop. This iterative tuning mechanism highlights the empirical nature of suspension optimization, where performance improvements are achieved through the integration of standardized methods and real-world observations.

4.3. Key Considerations in Tuning

The tuning process must adhere to several critical principles to ensure that performance optimization does not compromise overall system integrity. One of the most important considerations is the balance between comfort and handling. Excessive emphasis on comfort may result in reduced vehicle stability, while prioritizing handling can lead to a harsh riding experience. Achieving an optimal balance requires careful calibration based on vehicle positioning and user expectations.

In addition, durability verification must be conducted alongside performance tuning. Long-term fatigue testing is necessary to ensure that parameter adjustments do not introduce new failure risks, such as accelerated component wear or damping degradation. Cost control also plays a crucial role in the tuning process, as main engine manufacturers operate under strict budget constraints. Therefore, optimization strategies must prioritize cost-effective solutions that achieve the desired performance without unnecessary complexity. These considerations demonstrate that tuning is not merely a technical adjustment process, but a comprehensive decision-making activity within an industrial and economic context.

5. Conclusion and Prospect

This study, grounded in the practical demands of main engine manufacturers, systematically analyzes the design principles and tuning methodologies of suspension systems for motorcycles, mopeds and electric two-wheelers. The findings indicate that demand differentiation across vehicle categories serves as the primary driver of suspension design, requiring targeted adjustments in parameters, structural configurations and tuning strategies. At the same time, effective suspension development depends on balancing multiple factors, including durability, adaptability, comfort, handling performance and cost efficiency, all of which must be aligned with real-world production and application scenarios.

Looking forward, the evolution of the electric two-wheeler industry is expected to further reshape the technical requirements for suspension systems. Emerging trends such as intelligent adjustment, adaptive damping and lightweight design will play an increasingly important role in improving vehicle performance and user experience. In this context, suspension systems are likely to evolve toward more integrated and responsive solutions that can dynamically adapt to varying driving conditions. By organizing existing engineering practices within a structured analytical framework, this study provides a practical reference for suspension system development while also contributing to broader discussions on demand-driven engineering and technological adaptation in modern manufacturing systems.

Author Contributions:

Hongqin Wu contributed to the conceptualization, methodology of the study, and supervised the overall project, and coordinated the research process of the study. Xuhui Yang performed data analysis and conducted the first draft of the manuscript. All authors have read and agreed to the published version of the manuscript.

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