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Engineering Standards and Industrial Performance: An Interdisciplinary Study of Motorcycle Shock Absorber Design and Verification

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Abstract

This study examines the role of technical standards in shaping industrial practices through a case analysis of motorcycle shock absorber design and verification under the group standard T/ZZB 3029—2022. Moving beyond a purely engineering perspective, the paper adopts a socio-technical approach to explore how standardization frameworks influence product performance, quality control systems, and industrial governance in the motorcycle manufacturing sector. Drawing on practical R&D experience in customized suspension systems for original equipment manufacturers (OEMs), the study analyzes three key technical domains—spring design, damper tuning, and structural strength verification—within the institutional constraints of standardized requirements. It further investigates the full lifecycle quality assurance mechanisms, including ex-factory inspection, type testing, and failure protection, highlighting how standardized procedures contribute to risk mitigation and performance reliability. The findings suggest that the implementation of T/ZZB 3029—2022 not only enhances technical consistency and safety performance but also establishes a data-driven and process-oriented quality governance model. This model facilitates coordination between manufacturers and suppliers, supports differentiated product development, and strengthens the regulatory infrastructure of the industry. By integrating engineering practice with institutional analysis, this study contributes to interdisciplinary discussions on the relationship between technical standards, industrial innovation, and socio-economic development. It provides empirical insights into how standardization functions as both a technological and organizational mechanism in modern manufacturing systems.

Keywords: Standardization Governance; Industrial Coordination; Spring Design; Damper Tuning; Structural Strength Verification; Quality Control

1. The Core Role of Shock Absbers in Vehicle Performance

Motorcycle shock absorbers are core components of vehicles, which directly affect the driving safety and riding comfort of vehicles. Through the elastic deformation of springs and the damping effect of dampers, they effectively absorb road impacts and attenuate vehicle body vibrations, avoiding out-of-control situations such as bouncing and rolling during vehicle driving. From a dynamic systems perspective, the shock absorber plays a critical role in maintaining tire-ground contact stability. When a vehicle travels over uneven road surfaces, the suspension system must respond rapidly to external excitations. If the damping force is insufficient or mismatched, excessive oscillations may occur, leading to reduced adhesion between the tire and the road surface. This not only affects handling performance but also increases braking distance and rollover risk under extreme conditions. Therefore, the design and performance optimization of shock absorbers are not only related to comfort but are fundamentally linked to vehicle safety performance.

Our company specializes in customizing suspension systems for main engine manufacturers of motorcycles, mopeds and electric two-wheelers. In the process of R&D and customization, meeting the technical requirements of T/ZZB 3029—2022 standard is the primary R&D goal. This standard covers the entire process of shock absorbers from material selection, design and R&D, production and testing to quality control, clarifies various core technical indicators and unified test methods, and provides standardized technical guidelines for the industry (Zhejiang Brand Construction Federation, 2022).

In practical engineering applications, the implementation of this standard enables the transformation of empirical design into data-driven design. Traditional shock absorber design often relied on iterative testing and experience accumulation, which resulted in long development cycles and unstable performance consistency. By contrast, the standardized framework defined in T/ZZB 3029—2022 establishes clear boundary conditions and evaluation criteria, allowing engineers to carry out targeted parameter optimization and rapid verification (State Administration for Market Regulation, & Standardization Administration of the People's Republic of China, 2009).

Relying on this standard, we can ensure that customized shock absorbers not only meet the overall vehicle performance requirements of main engine manufacturers, but also conform to the unified industry safety and quality requirements. At the same time, the standard promotes consistency in product performance across different production batches, thereby enhancing supply chain coordination efficiency and reducing quality fluctuation risks in large-scale manufacturing environments.

2. Key Links in the Design of Shock Absorbers

2.1. Spring Design

Springs are the core elastic elements of shock absorbers, and their performance directly determines the basic shock absorption effect of shock absorbers. Two core indicators, rigidity accuracy and durability, must be strictly controlled in the design. The rigidity deviation of springs shall be strictly controlled within ±6%.

In engineering practice, spring stiffness is not only a static parameter but also a dynamic characteristic that influences the natural frequency of the suspension system (Kulkarni et al., 2024). If the stiffness is too high, the system becomes overly rigid, resulting in poor ride comfort and increased transmission of road shocks to the vehicle body. Conversely, if the stiffness is too low, excessive suspension travel may occur, leading to instability during high-speed driving or cornering. Therefore, achieving precise stiffness control is essential for balancing comfort and handling performance.

We use computer-aided design software to simulate and analyze the key dimensions of springs such as wire diameter, number of coils and free height, and accurately calculate and verify the spring rigidity parameters, ensuring that the springs meet the accuracy standard of limit deviation grade not lower than Grade 2 in GB/T 1239.2, and guaranteeing the accuracy of spring dimensions and performance from the source of design.

Furthermore, finite element analysis (FEA) is introduced to evaluate stress distribution under different loading conditions. By simulating cyclic loading and extreme deformation scenarios, potential stress concentration areas can be identified in advance, allowing structural optimization to be carried out during the design phase rather than after failure occurs.

Durability is an important assessment point in spring design (Kong et al., 2022). According to the requirements of T/ZZB 3029—2022 standard, after a spring completes 200,000 compression tests continuously with the working stroke, the permanent deformation shall not be greater than 2% of the free height before the test. This design requirement can effectively ensure the performance stability of the spring during the long-term driving of the vehicle and avoid the failure of the shock absorber caused by the elastic attenuation of the spring.

In addition, surface treatment processes such as shot peening are often applied to improve fatigue resistance. By introducing residual compressive stress on the surface, the initiation and propagation of fatigue cracks can be effectively suppressed, thereby extending the service life of the spring under high-frequency loading conditions.

2.2. Damper Tuning

Dampers are key components for controlling the vibration attenuation of shock absorbers (Xu et al., 2023; Fayyaz et al., 2025). Their tuning shall be carried out around three core indicators: indicator characteristics, speed characteristics and temperature characteristics, to ensure that the damping effect is adapted to the vehicle driving requirements.

From a functional perspective, damper tuning essentially involves shaping the force–velocity relationship of the damping system. This relationship determines how the shock absorber responds to different excitation frequencies and amplitudes. A well-tuned damper can provide low resistance at small amplitudes to improve comfort, while delivering high resistance under large impacts to enhance safety.

In the indicator characteristic test, the buffer resistance of the front shock absorber shall not be less than 200% of the recovery resistance. This requirement can ensure that when the vehicle encounters sudden road impacts, the shock absorber can quickly compress the buffer stroke to absorb impact energy and avoid violent shaking of the vehicle body.

The resistance tolerance of speed characteristics shall be designed differently according to vehicle positioning (Chang & Morlok, 2005). The recovery resistance tolerance of the front damper of ordinary motorcycles and mopeds is ±(13% Ff+20) N, which balances the comfort and driving stability of daily driving; the compression resistance tolerance of the rear damper of racing motorcycle shock absorbers is ±(10% Fy+20) N, meeting the handling requirements of racing motorcycles for high-speed cornering and extreme driving.

This differentiated design strategy reflects the necessity of adapting suspension characteristics to specific usage scenarios. For commuter vehicles, emphasis is placed on comfort and stability under moderate speeds, whereas for high-performance vehicles, rapid response and precise control under dynamic conditions are prioritized.

The temperature characteristics need to verify the performance stability of the shock absorber under extreme temperatures. The standard clearly requires that the recovery resistance attenuation rate of the shock absorber shall not be greater than 25% in a high-temperature environment of 100℃, ensuring that the shock absorber can maintain a stable damping effect under the working condition of long-term vehicle driving and high temperature.

In addition, low-temperature performance is equally critical, especially in cold regions. At low temperatures, the viscosity of damping oil increases significantly, which may lead to excessive damping force and reduced responsiveness. Therefore, the selection of damping oil and sealing materials must take into account the full temperature range of operating conditions.

2.3. Structural Strength Verification

Structural strength is the foundation for the safe operation of shock absorbers. Strict verification must be carried out from two aspects: the strength of core components and the quality of welded parts in the design. As a key connecting component of the shock absorber, the lifting ring shall have a tensile strength of not less than 15kN; as the main load-bearing component of the shock absorber, the aluminum cylinder shall have an axial static failure strength of not less than 15kN. By controlling the strength of core components, it is ensured that they can bear the maximum load during vehicle driving.

Beyond static strength verification, dynamic load analysis is also essential. During real driving conditions, shock absorbers are subjected to complex multi-axial loads, including impact loads, cyclic loads, and torsional stresses. Therefore, fatigue strength evaluation under variable amplitude loading is necessary to ensure long-term reliability.

Welded parts are the weak links of the structural strength of shock absorbers, so the welding quality must be strictly controlled. The welded parts shall be flat and uniform, without defects such as weld bumps, burn-through, slag inclusion, cracks, air bubbles and spatter.

At the same time, the welded parts shall pass a durability test of 1,000,000 vertical vibrations to verify the stability of the welded parts in the vibration environment of long-term vehicle driving and avoid potential safety hazards such as weld breakage and fracture. Non-destructive testing methods such as ultrasonic inspection and magnetic particle testing are also introduced in the production process to detect internal defects in welded joints, thereby improving overall structural reliability.

3. Rigorous Testing and Quality Control

3.1. Ex-factory Inspection

Ex-factory inspection is a key link to ensure the qualification of each shock absorber leaving the factory, which is carried out by sampling inspection (Xie et al., 2024). Products produced continuously with the same specification and process are regarded as one batch, and 4 products are randomly selected from each batch for testing, focusing on the detection of core items such as appearance, dimensional accuracy and damper flexibility.

In terms of dimensional accuracy control, the allowable deviation of the free length of the front shock absorber is ±1.5mm, and that of the rear shock absorber is ±1.0mm. Precise dimensional control can ensure that the shock absorber is accurately matched with the vehicle frame, transmission system and other components, avoiding problems such as installation interference and performance mismatch. The appearance inspection shall ensure that the electroplated and coated surfaces are smooth, flat and uniform in color; the damper inspection requires that the front and rear shock absorbers move flexibly during compression and extension without jamming, metal impact noise and abnormal friction sound, and the shock absorbers have no oil leakage whether placed horizontally or upside down.

3.2. Type Inspection

Type inspection is a comprehensive verification of the overall performance of shock absorbers. 10 samples shall be randomly selected from the same batch of products that have passed the ex-factory inspection to complete the full-item performance test, covering multiple dimensions such as performance, environmental adaptability and durable use.

The core test items include temperature characteristic test, which verifies the resistance change of the shock absorber in the extreme temperature range of -20℃ to 100℃ to ensure the performance stability of the shock absorber under extreme high and low temperature working conditions; dust and muddy water resistance test of the dust cover, which requires that after 1,000,000 tests, no dust or muddy water enters the inner lip of the dust seal and the lip of the oil seal, and the components have no damage, deformation and abnormal wear, protecting the internal components of the shock absorber from external corrosion; surface treatment corrosion resistance test, which requires that the electroplated layer pass a 24-hour neutral salt spray test with a surface corrosion resistance grade of not less than Grade 8, improving the service life and adaptability of the shock absorber to complex environments.

3.3. Failure Protection Design

Failure protection is an important means to ensure the long-term stable operation of shock absorbers. Targeted protection measures and testing requirements shall be formulated for different failure risk points of shock absorbers. For inflatable shock absorbers, the gas rebound force index must be strictly controlled to ensure that it meets the requirements of product design and technical documents, avoiding a sharp drop in shock absorption performance caused by gas leakage and abnormal pressure.

Anti-foaming characteristic is an important detection index of dampers, which requires that the damper has no obvious abnormal noise during the test, and the maximum fluctuation rate of the three measured indicator diagrams does not exceed 25%. This requirement prevents the shock absorber oil from generating foam during high-speed vibration, avoids the impact of foam on damping transmission efficiency, and ensures that the shock absorber will not have foaming failure problems under complex driving conditions.

4. Technical Value of Standard Implementation

The implementation of T/ZZB 3029—2022 standard provides a unified and standardized technical benchmark for the motorcycle and moped shock absorber industry, and its core technical value is reflected in three aspects: customized R&D, full-process control and data-based support. First, it clarifies the graded technical indicators of products. According to the different application scenarios of ordinary motorcycles, sports motorcycles and racing motorcycles, it formulates differentiated resistance tolerance standards for shock absorbers, meeting the customized R&D needs of different main engine manufacturers and vehicle models, making the design and tuning of shock absorbers more targeted and able to accurately match the driving and handling needs of various vehicle models. Second, it standardizes the full-process test and control requirements, forming a closed-loop quality control system from raw material performance testing, component design verification to finished product ex-factory inspection and type inspection, ensuring that every link of shock absorbers from R&D and design to finished product delivery meets the standard requirements and improving the overall product quality of the industry. Third, it provides scientific data support for customized R&D. The core data specified in the standard, such as the resistance attenuation rate not greater than 20% after 600,000 drum vibration tests, provides a unified reference basis for us to optimize spring parameters, tune damping curves and verify structural strength, helping us create high-performance and high-reliability customized suspension systems for customers.

5. Conclusion

T/ZZB 3029—2022 standard constructs a full-process quality control system for motorcycle and moped shock absorbers from material selection, design and R&D to production testing and life verification, which is the core technical basis for the design, verification and production of shock absorbers.

Relying on this standard, we accurately simulate spring dimensions and rigidity parameters through digital design technology to ensure that the spring rigidity accuracy meets the standard requirements; comprehensively verify the indicator characteristics and speed characteristics of dampers with the help of multi-speed program-controlled indicator dynamometers, and accurately tune the damping curves according to vehicle model requirements; simulate extreme road conditions and long-term vibration scenarios with double-acting fatigue test benches to comprehensively verify the structural strength and durability of shock absorbers.

Through standardized design processes and rigorous verification tests, we have realized the reliable operation of shock absorbers under complex driving conditions, which not only ensures that shock absorber products comply with the unified industry standards, but also can accurately match the overall vehicle customization needs of main engine manufacturers. It provides a core guarantee for the handling and driving safety of the whole motorcycle, and also offers high-quality suspension customization solutions that meet market demands for main engine manufacturers of motorcycles and electric two-wheelers.

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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