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Research on Vehicle Collision Safety Performance Optimization Based on CAE Technology

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Abstract: This study focuses on optimizing the collision safety performance of vehicles using CAE technology. By digitally simulating and analyzing the force and deformation of vehicle structures under different collision scenarios, the effectiveness of optimization in vehicle body design, material selection, and safety airbag systems is evaluated. The results indicate that measures such as using high-strength materials, optimizing vehicle body structure design, and improving safety airbag systems can significantly enhance the collision safety performance of vehicles and reduce the risk of occupant injury. This research provides effective methods and technical support for optimizing the collision safety performance of vehicles, which is of great significance for enhancing the overall safety performance of vehicles.

Keywords: CAE technology; vehicle collision; safety performance optimization; traffic accidents

1. Theoretical Foundation of Vehicle Collision Safety Performance

1.1. Vehicle Collision Dynamics Analysis

The theoretical foundation of vehicle collision safety performance involves vehicle collision dynamics. In vehicle collisions, the law of conservation of momentum is one fundamental principle, stating that the total momentum before and after the collision remains unchanged. Another important principle is the law of conservation of momentum, which governs the conservation of total momentum before and after the collision. The process of energy conversion in vehicle collisions is closely related to the principle of conservation of kinetic energy, including the conversion of kinetic energy into deformation energy, heat energy, and other forms. Key concepts in the analysis of vehicle collision dynamics often include impact force, collision time, and deformation capability. Impact force refers to the force exerted on the vehicle during a collision, with its magnitude closely related to the collision intensity. The collision time determines the degree of impact during the vehicle collision process. The vehicle's deformation capability is also an important indicator of collision safety performance, directly affecting the safety of occupants by absorbing and dissipating energy during a collision. In-depth research and analysis of vehicle collision dynamics can provide a better understanding of the mechanical laws and energy conversion mechanisms involved in vehicle collisions, thus providing a scientific basis for designing and improving vehicle structures and safety systems.

1.2 Evaluation Indicators for Collision Safety Performance

The evaluation indicators for vehicle collision safety performance are crucial standards for measuring the protection provided to drivers and passengers during collisions. The primary indicator is the safety score in collision tests, including comprehensive scores for various collision scenarios such as frontal collisions, side collisions, and side-slip collisions. When evaluating collision safety performance, it is also necessary to consider the vehicle's structural strength, rigidity, and the degree of deformation in different areas. Another important evaluation indicator is occupant space protection performance, including assessments of head and neck protection, chest protection, and abdominal protection for occupants. By simulating the ability of active safety protection systems such as airbags and seats to withstand and dissipate energy, the effectiveness of protecting occupants during collisions can be evaluated. Evaluation of vehicle rollover protection performance and pedestrian protection performance is also needed to comprehensively assess the overall safety performance of vehicles in different collision situations.

1.3 Factors Influencing Collision Safety Performance

Vehicle collision safety performance is influenced by various factors, including vehicle structure, materials, safety systems, and more. The structural design and impact resistance of various parts such as the front and rear body, doors, and roof are key factors affecting collision safety performance. The selection of vehicle materials also has a significant impact on collision safety performance; for example, the use of high-strength steel can improve the vehicle's resistance to compression and deformation after a collision. The performance of active safety systems such as pre-collision systems and airbag systems directly affects collision safety performance. Additionally, the driving behavior and safety driving skills of drivers are important factors influencing collision safety performance. Prudent driving, adherence to traffic rules, maintaining good vehicle conditions, and driving skills can reduce the likelihood of collision accidents and minimize the degree of harm in the event of a collision. Environmental factors such as road conditions and weather conditions also directly affect vehicle collision safety performance; good road conditions and suitable weather conditions help reduce the risk of accidents.

2. Application of CAE Technology in Vehicle Collision Safety Performance Analysis

2.1 Establishment and Validation of Finite Element Models

Computer-Aided Engineering (CAE) technology plays a crucial role in the analysis of vehicle collision safety performance, with finite element analysis being one of its important tools. In CAE technology, establishing accurate and reliable finite element models is a critical step. This involves modeling various components of the vehicle, including structure, materials, and connections, and setting collision conditions and simulation parameters to construct a complete vehicle finite element model. The accuracy and precision of the model are crucial for the reliability and practicality of the analysis results. Validation of the finite element model is also indispensable. This process involves comparing the finite element model with actual collision test results to verify the accuracy and effectiveness of the model. The validation involves comparing data such as forces and deformations of the vehicle in different collision scenarios to determine the fidelity of the model and the credibility of the simulation results. Through the establishment and validation of finite element models using CAE technology, simulations of various collision scenarios and solutions can be conducted in a relatively short time, providing a scientific basis for vehicle design and optimization of collision safety performance.

2.2 Collision Process Simulation and Result Analysis

One of the applications of CAE technology in the analysis of vehicle collision safety performance is the simulation of collision processes and analysis of results. Based on the structure and material properties of the vehicle, accurate finite element models are established, including various parts such as the body structure, chassis, and doors. Collision parameters such as speed and angle are set for the simulation. Digital simulation of the collision process is conducted by setting collision simulation conditions and performing finite element analysis of the collision process to observe the distribution of forces and deformation of the vehicle during collision. Based on data such as collision kinetic energy, instantaneous velocity, and mass distribution, the behavior of the vehicle during collision is simulated. The results of the collision are analyzed, including collision forces, deformation conditions, and stress states of the vehicle based on simulation results. The forces on various parts of the vehicle, such as the body structure, seats, and airbags, are examined to determine if they can provide effective protection. Furthermore, the degree of injury to occupants and survival space during the collision is evaluated. The use of CAE technology enables a more intuitive and accurate assessment of the vehicle's response and effectiveness during collision, providing a scientific basis for the improvement of vehicle design and collision safety performance.

2.3 Simulation-Based Collision Safety Performance Evaluation

Another application of CAE technology in the analysis of vehicle collision safety performance is simulation-based evaluation of collision safety performance. Setting collision scenarios and conditions is crucial before simulation analysis begins. Parameters such as collision speed, angle, and collision objects need to be set based on actual conditions to ensure that the simulation process corresponds to real collision environments. Collision simulation analysis is conducted by establishing a finite element model of the vehicle and performing collision simulation analysis using finite element analysis software. The forces, deformations, and stress conditions of the vehicle during collision are simulated, and the distribution of forces on the vehicle structure and the load-bearing capacity of key components are evaluated. The damage to the vehicle and occupants after the collision is assessed. Through analysis of the simulation results, the performance of the vehicle under different collision scenarios is evaluated. Changes in occupant survival space, response of active safety systems, etc., are observed, and the vehicle's ability to protect occupants after the collision is determined. Based on the simulation results and evaluation data, improvement plans are formulated. By identifying issues and deficiencies in the vehicle's collision performance through collision safety performance evaluation, corresponding improvement suggestions and design optimization plans are proposed to enhance the vehicle's collision safety performance.

3. Exploration of Methods for Optimizing Vehicle Collision Safety Performance

3.1 Optimization of Body Structure Design

Optimizing the collision safety performance of vehicles is one of the crucial tasks in vehicle design and manufacturing, with the optimization of body structure design being a key aspect. In body structure design, selecting high-strength steel or other advanced materials for critical parts such as doors and roofs enhances the overall structural strength of the vehicle. Introducing deformation zones capable of absorbing collision energy and designing appropriate deformation paths effectively mitigates impact forces during collisions. To enhance the vehicle's protective performance during collisions, adding collision buffer zones and absorption structures in the body design, such as controllable deformation components or energy absorbers, reduces the impact on the overall vehicle body and minimizes injuries to drivers and passengers. Optimizing body configuration and strengthening body connection points by adjusting the body configuration, such as adding reinforcement ribs and increasing connection points, enhances the overall rigidity of the vehicle body, increases the deformation path of the body, and effectively improves the stability and protective performance of the vehicle during collisions. Utilizing CAE technology for simulation analysis enables digital simulation of the body structure, simulating force and deformation conditions of the vehicle under different collision scenarios, evaluating the strength and impact resistance of the body structure, and providing a scientific basis for design optimization.

3.2 Improvement of Material Mechanical Performance

Improving the mechanical performance of materials is a key strategy in optimizing vehicle collision safety performance. Using advanced high-strength steel or composite materials, high-strength steel with higher tensile and compressive strength significantly enhances the vehicle's collision resistance when applied in body structures. Composite materials such as carbon fiber reinforced composites have higher specific strength and energy absorption performance, enabling lighter body designs while maintaining excellent collision resistance. Optimizing the ductility and fracture toughness of materials plays a crucial role in the collision process, directly affecting the deformation mode and degree of the vehicle during collisions. Adjusting material chemical composition and heat treatment processes to improve material ductility and fracture toughness makes the body more resilient and better at absorbing collision energy. Developing new energy-absorbing materials and structures using innovative energy-absorbing materials and structural designs such as metal foams and material foams achieve more efficient energy absorption, effectively mitigating impact forces during collisions and protecting vehicle occupants' safety. Combining simulation technology for material mechanical performance evaluation, integrating CAE technology for digital simulation analysis of material mechanical performance, enables a more intuitive and accurate assessment of deformation and failure behavior of different materials under collisions, providing a scientific basis for optimizing vehicle collision safety performance.

3.3 Optimization of Airbag Systems

The airbag system rapidly inflates to form a protective cushion during collisions, effectively cushioning the impact between occupants and the vehicle's interior structure, thereby reducing injuries to occupants caused by collisions. Enhancing the coverage and deployment design of airbag systems requires considering the occupant protection needs under different collision scenarios, including frontal, side, and rollover collisions. The design should ensure that airbags can rapidly inflate in various collision directions and positions to provide effective protection. The inflation speed and pressure of the airbag system directly affect the inflation response time and protective effect during collisions. By adjusting the design and performance parameters of the airbag inflation system, a faster and smoother inflation process can be achieved to form effective protective airbags in the shortest possible time. Optimization with sensors and intelligent control systems utilizes advanced sensor technology and intelligent control systems to monitor and analyze collision parameters in real-time. This enables the prediction of occupant positions and collision severity before collisions, allowing precise control of airbag deployment and inflation processes to provide personalized protection. Conducting collision tests and simulation validation evaluates the performance of airbag systems in real collision scenarios and verifies whether airbag deployment and inflation meet design requirements, providing technical support for continuous system optimization.

3.4 Improvement of Electronic Stability Systems

In optimizing vehicle collision safety performance, improving electronic stability systems such as Electronic Stability Control (ESC) is a crucial strategy. Enhancing the precision and rapid response of electronic stability systems by optimizing sensor technology and control algorithms allows for more accurate monitoring of vehicle motion status and driving behavior. It enables timely identification of hazardous situations and prompt intervention measures to ensure the vehicle maintains good controllability in emergency situations. Optimizing the integration of electronic stability systems with vehicle dynamic control systems integrates electronic stability systems with vehicle dynamic control systems such as braking systems and vehicle traction control systems for efficient collaboration, enabling dynamic vehicle control and improving vehicle stability and controllability. Comprehensive optimization with other active safety systems integrates electronic stability systems with other active safety systems such as adaptive cruise control, forward collision warning systems, etc., to achieve synergy among multiple safety systems, providing comprehensive safety protection for vehicle drivers. Performance evaluation of electronic stability systems using simulation technology conducts comprehensive simulation analysis and performance evaluation of electronic stability systems in various driving scenarios using CAE technology and simulation platforms, providing scientific support for system improvement and optimization.

Conclusion

In conclusion, the application of CAE technology in the optimization of vehicle collision safety performance provides us with an efficient and reliable analysis tool. Through digital simulation and modeling, we can more accurately assess the details of the forces and structural deformations experienced by vehicles during collisions, providing important references for design optimization. In the future, we will further explore the application of new materials, new structures, and intelligent systems to continuously improve the collision safety performance of vehicles. Through continuous research and innovation, we will strive to ensure that vehicles provide the best protection for occupants during collisions, making greater contributions to road safety. Let us work together to build safer and more reliable vehicles.

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