Overview of suspension system dynamics analysis

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Abstract. The control strategy of vehicle suspension system model has been gradually transferred to the modern control optimization algorithm, and the traditional suspension has gradually been unable to meet the vehicle's pursuit of high performance. Starting from vehicle modal analysis, the development status of suspension model building method, category and control strategy is described respectively. On this basis, the current development difficulties and trends are analyzed.

1. Introduction

In the process of vehicle driving, vibration will inevitably occur due to road excitation and engine vibration, which will affect the riding comfort of passengers. For transport vehicles, the goods will be damaged due to excessive vibration during moving forward. For example, in a certain place in 2000, the main cause of ammunition explosion accident was the excessive vibration during ammunition transportation, which led to the failure and explosion of abandoned Ammunition Fuze. The accident caused more than 300 casualties. Therefore, it is of practical significance to optimize the control strategy and suspension structure of vehicle suspension system to reduce the vibration energy of vehicle body. In other words, when the excitation can not be changed or difficult to change, it is an effective method to reduce the vibration response of transport vehicles by studying the control strategy of vehicle suspension system and optimizing the suspension structure.

2. Modal analysis of vehicle vibration

Road roughness and body response caused by powertrain seriously affect people's requirements for comfort and safety [1]. Therefore, it is the basis of vehicle modal analysis and dynamic analysis. Some scholars use the finite element method to analyze the natural frequencies and modes of vehicle components, and carry out structural optimization [2-8]. Finite element method can make complex engineering problems simple and clear and has been widely used. Although the finite element method has high accuracy and floating degree, it has higher requirements for modeling level, boundary conditions and load conditions. Therefore, some scholars analyze vehicle mode through theoretical modeling and simulation [9-11]. Generally, theoretical modeling can only solve relatively simple models. For complex models, the workload is heavy and difficult to model. Some scholars directly use sensors to collect data from actual vehicles, and then carry out pattern recognition [12-16].

Vehicle pattern recognition is the basis of vehicle vibration control. There are two common vibration reduction methods. One is a passive damping structure composed of spring, shock absorber (shock absorber) and guide mechanism [17-22]. The other is damping materials, which rely on the characteristics of polymer materials such as rubber and polyurethane to absorb the response energy.
generated during vehicle driving [23-27]. There is a certain relationship between damping structure and damping material, but the emphasis is different.

Generally speaking, passive vibration absorption by dynamic absorber only depends on the response mode of transfer function to excitation, and there is no feedback, so the vibration reduction effect of active suspension is poor. Active suspension with adjustable control strategy has energy consumption problem [28-30]. For the research of vehicle suspension system, the appropriate model should be selected according to the research purpose. At present, there are three suspension system models: 1/4, 1/2 and full vehicle model.

3. Suspension model
Vehicle suspension model can be divided into 1/4, 1/2 and whole vehicle. The 1/4 model does not consider the pitch and roll motion of the vehicle, while the 1/2 model considers the pitching motion in the process of vehicle forward, while the whole vehicle suspension system model considers both the pitch and roll motions [31].

The 1/4 suspension system model includes two degrees of freedom, one is the body degree of freedom, the biggest advantage of the model is simple structure, easy to carry out mathematical modeling and simulation analysis; based on the 1/4 suspension system model, the semi vehicle suspension system's degree of freedom is extended by four degrees of freedom, and the body's two degrees of freedom. The model further improves the description of the actual situation of vehicles. The suspension system model of the whole vehicle is the most complex. The model contains eight degrees of freedom, which provides three degrees of freedom for the body.

The above three models are the most basic models of vehicle vibration reduction, most of the current research is based on the simplification or improvement of the above three models. At the same time, Zhang [31] and others found that under the same excitation conditions, the frequency of the highest peak in the frequency domain is the same. However, the quarter suspension system model does not consider the energy offset caused by vehicle pitching motion, so when the peak value appears in the frequency domain, the simulation results of body response power are higher than those of the latter two models (half vehicle suspension system model and vehicle suspension system model), and the response power of frame system model is equal, because it usually does not reflect the lateral response under given road excitation Road roughness. Therefore, if it is necessary to improve the control strategy or suspension structure, the first two models have little effect on the results; if the response energy received is studied, such as fatigue strength, energy acquisition, etc. the vehicle suspension system model should be used.

4. Suspension type
Suspension refers to the sum of all parts between the body and the wheel, which is mainly composed of spring, shock absorber and steering mechanism. It has two functions: one is to transfer the force and torque from the tire, which is usually connected with the knowledge of power spectrum [30]; the other is to mitigate the impact load from the ground [32] At present, suspension system can be divided into active suspension, semi-active suspension and passive suspension.

4.1. Active suspension
Active suspension means that it can dynamically adjust the suspension parameters according to the driving conditions of the vehicle to make it in the best damping state and improve the driving comfort and handling stability.

For example, it depends on the control of magnetorheological damper [33], electro- magnetic damper [34], piezoelectric damper [34].

4.2. Semi active suspension
As active suspension controls the actuators that produce force, it consumes external energy. As a result, the semi-active suspension model has attracted more and more attention for its relatively excellent performance and no energy input. Semi-active suspension can adjust suspension damping according to
road spectrum information and body state, and then improve vehicle ride comfort. Therefore, the improvement of semi-active suspension is mainly the improvement of control strategy, and some scholars have modified the structure of semi-active suspension Good [35-36].

4.3. Passive suspension
Traditional passive suspension, relying on its simple structure and strong robustness, still has great practical value. The current research on passive suspension mainly focuses on the improvement of material or structure [37-39].

5. Control strategy
At present, the basic idea to solve the optimal control problem of active suspension is to adopt control strategies to improve the ride comfort of the vehicle. On this basis, some scholars proposed the evaluation function of the optimal control signal [40], and on this basis, designed a series of optimal train controllers. There are two main control methods for vehicle suspension problems: one is a rule-based control strategy; the other is an optimized control strategy [41]. The rule-based control strategy is to monitor the effectiveness of the rules in the driving process. The formulation of these rules does not necessarily require prior knowledge of driving knowledge. These methods can be divided into deterministic methods and methods based on fuzzy rules [42]. The rule-based control method mainly relies on the idea of balancing the load, that is, at a specific engine speed, every moment the vehicle is driving will force the vehicle to return to the best efficiency point.

5.1. Method based on fuzzy rules
Regarding the suspension system as a multi domain, nonlinear and time-varying object, fuzzy logic seems to be the most reasonable method to solve this problem. In fact, the decision-making characteristics of fuzzy logic can be used instead of deterministic rules to realize real-time suboptimal vibration reduction and energy absorption strategy and improve the fault tolerance of the system [43]. In other words, fuzzy logic controller is an extension of the traditional rule-based controller [44]. The main advantages of the methods based on fuzzy rules are as follows: (1) robustness, because they can tolerate imprecise measurements and component changes [45]; (2) adaptability, because the fuzzy rules can be easily adjusted if necessary [46]. At the same time, because the self-adaptability of fuzzy rules is the same as that of intelligent algorithms such as neural network algorithm, the two are often used together [47-48]. The method based on fuzzy rules is composed of traditional fuzzy strategy [49-52], fuzzy adaptive strategy [53-55] and fuzzy prediction strategy [56-57].

5.2. Rule based deterministic approach
The representative of the rule-based deterministic method is the modern control theory [58-60]. The root locus method or the frequency response function method are used to design the adjustment controller to realize the active control of the vehicle suspension system. The representative of the method is PID control [61], which also evolves various improved PID control algorithms [62-65]. But fuzzy PID controller is better than PID controller with fixed gain parameters. In addition, there are LQG optimization algorithm [66], strategy iterative control [67], adaptive control [68], practical static feedback control [63], etc.

5.3. Control strategy based on Optimization
5.3.1. Global optimization. Based on the Hamilton Jacobi Bellman optimization principle, a theory for solving the optimal control of vehicle suspension is proposed. Compared with the classical LQR theory, the control effect of the suspension system with uncertain parameters is improved [69]. The purpose of global optimization is to make the whole suspension system rely on the cost function to achieve the performance goal, so as to obtain the global optimal operation point under specific external excitation
It can be divided into linear programming [54, 70], control theory and method [71], dynamic programming [72], random DP [73], game theory [74] and genetic algorithm [75].

5.3.2. Real time optimization. Global optimization techniques are not directly applied to real-time optimization because they are accidental solutions. However, real-time optimization can be rapidly adjusted to the changes of external states. Real time optimization strategies can be divided into decoupling control [76] and robust control method [77].

6. Conclusion
In this paper, aiming at the practical problems of improving vehicle safety and transportation, consulting a large number of literatures, this paper analyzes the suspension type, model establishment and control strategy method of suspension vibration reduction. The performance of active suspension is very good, but it consumes energy. Based on this, some scholars rely on energy feedback suspension to solve this problem, but on the one hand, it is difficult to realize the whole process of active control and passive energy feedback at the same time; on the other hand, the power conversion between motor and generator is difficult to achieve completely seamless and efficient, and there will be a certain delay in the actual application process, which is not conducive to the efficient operation of energy feedback suspension [78]. In addition, the damping effect of traditional passive suspension cannot meet people's requirements for comfort and riding comfort, while the semi-active suspension between the two can meet the requirements of many people for vibration reduction performance and economy. At present, the research on semi-active suspension system mainly includes two aspects. One is the improvement of materials, such as the optimization of magnetorheological materials [79-80], or the use of water-based materials with superior performance and environmental protection; the other is the improvement of control algorithm, such as the introduction of Udwadia kalaba method [81]. Considering the nonlinear relationship of suspension system, the traditional linear model cannot meet its needs. Therefore, modern control strategies such as fuzzy control, adaptive control and other nonlinear control methods have been developed rapidly. The suspension control strategy combining adaptive fuzzy controller and magnetorheological damper has also achieved good ride comfort and vehicle handling in practical application. However, the traditional linear control model and the modern nonlinear control model have some errors. In recent years, neural network algorithm and genetic algorithm have been introduced into the control model to realize the nonlinear infinite approximation. Therefore, in the era of artificial intelligence, whether the self-learning ability of control system can be further improved, and the sensitivity and response speed of suspension system to external changes will become the development trend of future suspension control strategy. In addition, some scholars have improved the control strategy by using the delayed feedback model, but the experimental results are prone to produce chaos, so how to optimize the gain function to avoid chaos remains to be further studied.

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