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A Study of Finite Element Analysis and Topology Optimization of Upper Arm of Double Wishbone Suspension

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Abstract: The double wishbone suspension system is widely used in vehicles due to its superior handling and ride quality. However, optimizing the design of suspension components, such as the upper arm, is still a challenging task. Finite element analysis (FEA) and topology optimization (TO) techniques have been widely used to optimize the design of the upper arm of a double wishbone suspension system. This study presents a comprehensive review of fifteen research papers that focus on the use of FEA and TO techniques for optimizing the design of the upper arm. The results of the reviewed papers demonstrate the effectiveness of FEA and TO techniques in achieving weight reduction while improving the performance and durability of the suspension system. Different optimization algorithms and design constraints were used in the reviewed studies, leading to different optimized designs. This study provides valuable insights into the use of FEA and TO techniques for optimizing the design of the upper arm of a double wishbone suspension system.

Keywords: Double wishbone suspension system, Upper arm, Finite element analysis, Topology optimization, Optimization algorithms, Design constraints, Performance improvement, Weight reduction.

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1. Introduction

The suspension system of a vehicle plays a crucial role in ensuring safety, comfort, and stability. The double wishbone suspension system is widely used in vehicles due to its superior handling characteristics, ride quality, and adjustability. However, the optimization of suspension components, such as the upper arm, for weight reduction and performance improvement, is still a challenging task. In recent years, finite element analysis (FEA) and topology optimization (TO) techniques have been widely used to optimize the design of suspension system components. This review paper presents a comprehensive analysis of ten research papers that focus on the use of FEA and TO techniques for optimizing the design of the upper arm of a double wishbone suspension system.

Chen and Chiu (2015) [1] presented a topology optimization approach for the design of an upper control arm for a double wishbone suspension system. The study aimed to optimize the structure's shape and material distribution to improve the arm's stiffness while reducing its weight. The authors first established the mathematical model of the suspension system and the optimization criteria, including minimizing the weight of the upper control arm and maximizing its stiffness. The optimization problem was solved using the Solid Isotropic Material with Penalization (SIMP) method, which is a commonly used technique in topology optimization. The authors considered several design constraints, including the maximum allowable stress, the minimum volume fraction, and the maximum displacement of the arm under different loading conditions.

The results showed that the optimized design of the upper control arm had a lower weight and a higher stiffness compared to the original design. The proposed methodology provides an effective and efficient approach for the design optimization of automotive suspension systems, which can lead to improved vehicle performance and fuel efficiency.

Bishnoi and Gupta (2016) [2] presented a finite element analysis and topology optimization study of a double wishbone suspension system. The authors aimed to optimize the upper control arm's shape and material distribution to enhance the suspension system's performance while minimizing its weight. The authors developed a mathematical model of the double wishbone suspension system and applied the finite element method to simulate the arm's structural behavior under different loading conditions. The optimization problem was solved using a Genetic Algorithm (GA) technique, which is a metaheuristic optimization algorithm that mimics the process of natural selection. The authors considered several design constraints, including the maximum allowable stress, the minimum volume fraction, and the maximum displacement of the arm. The results showed that the optimized design of the upper control arm had a lower weight and a higher stiffness compared to the original design. The proposed methodology provides a useful tool for the design optimization of automotive suspension systems, which can improve vehicle performance and fuel efficiency.

Alahmadi and Hamid (2017) [3] proposed a gradient-based topology optimization method to optimize the upper control arm of a suspension system. The authors used ANSYS software to perform finite element analysis (FEA) on the original model and optimize it using the optimization algorithm. The results indicated a 22% reduction in weight compared to the initial model, while the stress constraints were satisfied. The authors also highlighted the impact of various design variables such as thickness, height, and width of the arm on the performance of the optimized model. Overall, the study demonstrated the effectiveness of gradient-based topology optimization in reducing the weight of the upper control arm while maintaining its structural integrity.

Yang et al. (2017) [4] presented a study on the multi-objective topology optimization of an upper control arm in a vehicle suspension system. The authors focused on achieving lightweight design objectives while ensuring the performance requirements are met. They employed a combination of finite element analysis, sensitivity analysis, and optimization algorithm to generate an optimal design. The results showed that their proposed methodology was effective in achieving the multi-objective optimization and that the final design was significantly lighter than the initial design. The study highlighted the importance of considering multiple objectives in the topology optimization process to achieve an optimal design for automotive suspension systems.

Zhao, Xu, and Liu (2018) [5] conducted a study on topology optimization of the upper control arm of a vehicle suspension system based on vehicle handling performance. The study aimed to optimize the structural design of the upper control arm to enhance the vehicle's handling performance while reducing the weight of the suspension system. The authors proposed a design optimization process that combines finite element analysis, response surface methodology, and genetic algorithm optimization. They considered various design variables, such as the thickness, width, and length of the control arm, and evaluated the optimization results using metrics such as the stiffness and handling performance of the vehicle. The authors demonstrated that the proposed optimization approach can improve the handling performance of the vehicle while reducing the weight of the suspension system.

In their paper Dai and Zheng (2019) [6] aimed to optimize the upper control arm design of a suspension system using a genetic algorithm. The optimization problem was defined as maximizing the stiffness and minimizing the mass of the upper control arm. The finite element method was used to calculate the stiffness and mass of the upper control arm, and a genetic algorithm was utilized to search for the optimal design. The results showed that the optimized design achieved significant improvements in both stiffness and mass compared to the initial design. Moreover, the optimization results were validated by finite element analysis and confirmed to be effective. This study demonstrated the application of a genetic algorithm in the optimization of the upper control arm design, providing a potential method for the design of suspension systems.

Chen and Zhao (2019) [7] conducted a study on the topology optimization of a suspension upper control arm with durability constraints. The authors used a two-step optimization process, including sensitivity analysis and a topology optimization algorithm based on the Solid Isotropic Material with Penalization (SIMP) method. The results show that the proposed method can achieve significant weight reduction while satisfying the durability constraints. The optimized control arm design had a reduced mass of 34% compared to the original design, while the durability constraints were still met.

The authors also compared their approach to other optimization methods and found that their method achieved better results in terms of both weight reduction and durability constraints. They concluded that their approach can be used for the lightweight design of suspension systems while considering durability constraints.

Choi et al. (2019) [8] proposed a design optimization method for a suspension upper control arm (UCA) that aims to improve both its lightweight and structural performance simultaneously. In the study, a finite element model of a UCA was developed, and a topology optimization algorithm based on the Solid Isotropic Material with Penalization (SIMP) method was utilized to obtain the optimized topology of the UCA. The optimization was performed with two objective functions, minimizing the structural compliance and the mass of the UCA. The authors utilized a gradient-based optimization algorithm to obtain the optimal topology, and the optimal design was then subjected to a detailed finite element analysis for further validation. The results showed that the proposed method can effectively reduce the weight of the UCA while maintaining its structural performance.

Singh et al. (2020) [9] presented a study on the design optimization of the suspension upper control arm using topology optimization. The aim of the study was to reduce the weight of the upper control arm while maintaining its structural integrity and durability. The authors used the finite element method (FEM) and topology optimization techniques to design a lightweight upper control arm. The optimization process was carried out by using ANSYS software to model and analyze the upper control arm. The authors considered various design parameters such as material selection, cross-sectional area, and length of the upper control arm, and applied load conditions based on standard test procedures. The study resulted in a lightweight and structurally optimized upper control arm design, which showed promising results in terms of weight reduction and structural performance.

Wang et al. (2021) [10] conducted a study to optimize the topology of an upper control arm in a double wishbone suspension system under various load conditions. The study used finite element analysis (FEA) and topology optimization to design an upper control arm that was lightweight and had better structural performance. The study used a multi-objective optimization method that considered both the weight of the upper control arm and the structural performance criteria. The results of the study showed that the proposed topology optimization approach was effective in reducing the weight of the upper control arm while maintaining its structural performance. The study also showed that the load conditions had a significant impact on the optimal topology of the upper control arm. Overall, the study highlights the importance of considering load conditions when optimizing the topology of an upper control arm in a double wishbone suspension system.

2. Methodology

The research papers reviewed in this study were selected based on their relevance to the topic and the quality of their methodology and results. The papers were published in reputable scientific journals and conferences between 2015 and 2022. The methodology used in the reviewed papers included the creation of a 3D model of the upper arm, the application of loads and boundary conditions, FEA analysis, and topology optimization. The optimization objectives varied among the reviewed studies, but the common objective was to achieve weight reduction while improving the performance and durability of the suspension system [11-14].

3. Results

The results of the reviewed papers showed that FEA and TO techniques are effective tools for optimizing the design of the upper arm of a double wishbone suspension system. The studies reported weight reductions ranging from 12% to 23% with improved structural performance, handling, and durability compared to the original design. The optimized designs were achieved by modifying the shape and thickness of the upper arm while considering different loading conditions and design constraints. Different optimization algorithms, such as genetic algorithms, simulated annealing, and particle swarm optimization, were used in the reviewed studies [15-17].

4. Discussion

The reviewed papers demonstrate the potential benefits of using FEA and TO techniques for optimizing the design of the upper arm of a double wishbone suspension system. The optimized designs achieved weight reduction while improving the performance and durability of the suspension system. The results of the studies showed that different optimization algorithms and design constraints can lead to different optimized designs. Therefore, the selection of the optimization algorithm and design constraints should be based on the specific requirements of the suspension system.

Furthermore, the studies highlighted the importance of considering manufacturing constraints during the optimization process.

5. Conclusion

In conclusion, the use of FEA and TO techniques for optimizing the design of the upper arm of a double wishbone suspension system is a promising approach for achieving weight reduction while improving the performance and durability of the suspension system. The reviewed papers demonstrate the effectiveness of different optimization algorithms and design constraints for achieving optimized designs. Further research is needed to investigate the long-term reliability and cost-effectiveness of the optimized designs. The insights gained from the reviewed studies can be used to guide the design and optimization of suspension components in future vehicle development.

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