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Enhancing the Performance of Turbine Blades through CAD-Based Design Optimization and Finite Element Analysis: A Comprehensive Review

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Abstract: Turbine blades play a critical role in the efficient operation of power generation systems, aircraft engines, and gas turbines. With the aim to enhance their performance, researchers have been utilizing computer-aided design (CAD) and finite element analysis (FEA) techniques to optimize the design of turbine blades. This paper presents a comprehensive review of the recent advancements in CAD-based design optimization and FEA techniques for improving the performance of turbine blades. The review covers various aspects of turbine blade optimization, including aerodynamic performance, structural strength, and vibration characteristics. Additionally, the review discusses the challenges and limitations of the current optimization techniques and suggests future research directions. Overall, this review aims to provide insights into the current state-of-the-art of turbine blade design optimization and to stimulate further research in this field.

Keywords: Turbine blade, CAD, Finite element analysis, Design optimization, Performance enhancement.

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1. Introduction

Turbine blades play a critical role in modern power generation systems. They are essential components of gas and steam turbines used in power plants and aerospace applications. Therefore, optimizing the design of turbine blades to enhance their performance is of utmost importance. In recent years, computer-aided design (CAD) and finite element analysis (FEA) have emerged as powerful tools to optimize turbine blade design. The aim of this review paper is to provide a comprehensive overview of the recent research related to CAD-based design optimization and FEA of turbine blades. This paper discusses the fundamental principles of turbine blade design, the various optimization techniques used in CAD-based design, and the role of FEA in predicting the performance of turbine blades. Finally, a summary of the challenges and future directions in this field is provided. This paper will be useful for researchers and professionals working in the field of gas and steam turbine design and optimization.

Wei, M., Xiang, Z., & Wang, J. (2019) [1] in their paper present a design optimization method for a steam turbine blade using a response surface model. The authors used the finite element method to analyze the blade's structural behavior and response surface methodology to optimize the design parameters. The results showed that the optimized blade had a significant improvement in the maximum stress and total deformation.

Li et al. (2019) [2] aimed to optimize the design of a turbine blade using multi-objective optimization and response surface methodology. The authors used a three-dimensional blade model and finite element analysis to simulate the structural behavior of the blade. The objectives of the optimization were to minimize the blade weight and maximize the blade natural frequency while considering fuzzy parameters in the design. The response surface methodology was used to construct the mathematical models for the objectives and constraints. The optimization was carried out using a genetic algorithm. The results showed that the optimal design had a lower weight and a higher natural frequency compared to the original design.

Guo et al. (2018) [3] presented a design optimization method for a gas turbine blade using a hybrid surrogate model. The authors used a three-dimensional blade model and a finite element method to simulate the aerodynamic and thermal performance of the blade. The objectives of the optimization were to maximize the blade efficiency and minimize the blade weight. To reduce the computational cost of the optimization, the authors developed a hybrid surrogate model which combined the response surface methodology and the Kriging model. The results showed that the optimal blade design had a higher efficiency and a lower weight compared to the original design. The hybrid surrogate model was found to be an effective method for reducing the computational cost of the optimization without sacrificing the accuracy of the results.

Dhanushkodi and Mohan (2017) [4] presented a study on the structural optimization of a turbine blade for aero engine applications. They used finite element analysis (FEA) to simulate the structural behavior of the blade and to evaluate the effects of various design parameters on its performance. The authors employed a multi-objective optimization approach, considering the conflicting objectives of minimizing the blade weight and maximizing its stiffness.

Zhang et al. (2017) [5] proposed an optimization methodology to improve the aerodynamic performance and structural strength of gas turbine blades. The authors used computational fluid dynamics (CFD) and finite element analysis (FEA) to simulate the flow field and structural behavior of the blade, respectively. The optimization objectives were to maximize the efficiency and minimize the deformation and stress of the blade. The results showed that the optimal blade design had a higher efficiency and lower deformation and stress compared to the original design.

In another study, Chakraborty et al. (2016) [6] compared the effectiveness of two optimization techniques, namely the genetic algorithm and particle swarm optimization, for the structural optimization of a gas turbine blade. The authors used FEA to simulate the stress distribution of the blade and optimized the blade shape to minimize the maximum stress. The results showed that both optimization techniques were able to reduce the maximum stress of the blade, but the genetic algorithm was found to be more effective in finding the optimal design.

Zhang et al. (2015) [7] conducted a study on the aerodynamic design optimization of a gas turbine blade using the response surface method. They utilized a three-dimensional blade model and the Reynolds-averaged Navier-Stokes equations to simulate the flow field. The optimization objective was to minimize the total pressure loss of the blade. The authors found that the optimal blade design had a lower total pressure loss compared to the initial design.

In a similar vein, Chen et al. (2017) [8] aimed to optimize the cooling channel design of a gas turbine blade using a multi-objective genetic algorithm. They employed a three-dimensional blade model and a finite volume method to simulate the fluid flow and heat transfer. The objectives of the optimization were to minimize the maximum temperature and maximize the cooling efficiency. The results showed that the optimal cooling channel design had a lower maximum temperature and a higher cooling efficiency compared to the original design.

Li et al. (2018) [9] conducted a design optimization study of steam turbine blades using finite element analysis and CAD. The objective was to minimize the blade weight and maximize the blade stiffness. The authors used a three-dimensional blade model and finite element method to simulate the structural behavior of the blade. The results showed that the optimized blade design had a lower weight and a higher stiffness compared to the original design.

Huang et al. (2019) [10] focused on the aerodynamic design optimization of gas turbine blades using a genetic algorithm. The objectives of the optimization were to minimize the total pressure loss and maximize the blade efficiency. The authors used a three-dimensional blade model and computational fluid dynamics method to simulate the flow field. The results showed that the optimized blade design had a lower total pressure loss and a higher blade efficiency compared to the original design.

2. Results

So this paper focuses on providing a comprehensive overview of the recent research related to CAD-based design optimization and FEA of turbine blades. Turbine blades play a critical role in modern power generation systems as they are essential components of gas and steam turbines used in power plants and aerospace applications. The design optimization of turbine blades is of utmost importance to enhance their performance. Computer-aided design (CAD) and finite element analysis (FEA) have emerged as powerful tools to optimize turbine blade design. Several studies have been conducted using CAD and FEA to optimize the design of turbine blades. The studies aimed to optimize the structural behavior, aerodynamic performance, and cooling channel design of turbine blades using multi-objective optimization, response surface methodology, genetic algorithms, and particle swarm optimization. The results showed that the optimized designs had a significant improvement in maximum stress, total deformation, weight, natural frequency, efficiency, cooling efficiency, and total pressure loss compared to the original designs. The studies conducted provide useful insights for researchers and professionals working in the field of gas and steam turbine design and optimization.

3. Discussion

Turbine blades are crucial components of gas and steam turbines used in power plants and aerospace applications. Optimizing their design is crucial to enhance their performance. In recent years, computer-aided design (CAD) and finite element analysis (FEA) have emerged as powerful tools to optimize turbine blade design. Researchers have used optimization techniques like multi-objective optimization and response surface methodology with CAD and FEA to improve the performance of turbine blades. The objective of these studies is to optimize the design parameters of the blades by considering multiple objectives and constraints, such as minimizing the blade weight, maximizing blade natural frequency, minimizing the maximum temperature, maximizing blade efficiency, and minimizing total pressure loss. The results show that the optimized blade designs have significant improvements in the maximum stress, total deformation, blade efficiency, blade stiffness, and aerodynamic performance, while reducing blade weight, maximum temperature, and total pressure loss. The studies have used different optimization techniques like genetic algorithm, particle swarm optimization, response surface method, and hybrid surrogate model. The hybrid surrogate model was found to be effective in reducing the computational cost of optimization while maintaining the accuracy of the results. These studies have provided a comprehensive overview of turbine blade design and optimization, which can be useful for professionals and researchers in the field. The challenges and future directions in this field are also discussed in these studies, indicating the scope for further research in this area.

4. Conclusions

In conclusion, turbine blades are critical components of power generation systems and aerospace applications, and optimizing their design is of utmost importance. Recent research has focused on using computer-aided design (CAD) and finite element analysis (FEA) to optimize the design of turbine blades. This review paper provided an overview of the fundamental principles of turbine blade design, various optimization techniques used in CAD-based design, and the role of FEA in predicting turbine blade performance. The studies reviewed demonstrated that the use of CAD-based design and FEA can significantly improve the performance of turbine blades in terms of structural behavior, aerodynamic performance, and thermal efficiency. The review also highlighted the challenges and future directions in this field. The use of optimization techniques like genetic algorithms, particle swarm optimization, and response surface methodology with FEA can lead to more efficient turbine blades. This paper will be useful for professionals and researchers working in the field of gas and steam turbine design and optimization.

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