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A REVIEW PAPER ON GAS TURBINE ROTOR BLADE

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ABSTRACT
Gas turbine rotor blades are vital components in gas turbine engines, tasked with extracting energy from the working fluid efficiently and reliably. These blades operate under extreme conditions, including high temperatures, pressures, and centrifugal forces, requiring advanced materials and precise engineering. The design process involves intricate aerodynamic considerations to optimize performance, with factors such as blade profile, twist, and cooling methods carefully tailored for each application. Manufacturing techniques including precision casting and advanced machining ensure the blades meet strict performance and durability requirements. Continuous advancements in materials and manufacturing technologies drive improvements in gas turbine blade performance contributing to more efficient and reliable .

LITERATURE SURVEY

Naveen Kumar Sahu [1] The gas turbine derives its power from harnessing the energy of combusted gases and high-pressure, high-temperature air as they expand through a series of stationary and rotating blade assemblies. Operating under these conditions, the turbine blades endure considerable stress. Firstly, centrifugal forces exert pressure on the blades due to their rapid rotation. Secondly, thermal stresses emerge from temperature differentials within the blade material.

Shyy Woei Chang [2] As gas turbine engines strive for greater power density and thermal efficiency, the push for higher turbine entry temperatures intensifies. This demand drives continuous advancements in metallurgy and cooling techniques to uphold the structural integrity of rotor blades. These blades operate at extreme speeds within a gas stream surpassing the melting point of their materials, necessitating robust engineering solutions to ensure durability and performance.

A T Puja Priyanka [3]: Turbine blades are pivotal components across multiple energy production sectors, including thermal and hydraulic power plants, gas turbine facilities, wind farms, and aviation. While the technology behind turbine blade construction has matured significantly, ongoing advancements, particularly in the realm of gas turbines, continue to progress steadily.

Taspia Shawkat Chowdhury [4]: This article provides a comprehensive exploration of the gas turbine, focusing on its thermal performance and failure analysis, which are crucial for enhancing efficiency and preventing future failures. By examining past failure case studies, it serves as a valuable resource for identifying root causes and guiding improvements. Cooling efficiency significantly influences turbine performance, thereby impacting thermal efficiency. Various methods and strategies are discussed to enhance both thermal performance and cooling efficiency of gas turbines, offering pathways for advancement in turbine technology.

Ajeet Kumar Rai [5]: This study focuses on analyzing the first stage rotor blade of a two-stage gas turbine using ANSYS 12, a robust Finite Element Software, to assess both its structural and thermal characteristics. By simulating temperature distribution within the rotor blade, thermal stresses are evaluated. The analysis encompasses three different materials: titanium alloy, stainless steel alloy, and Aluminum 2024 alloy. Static, thermal, and modal analyses are conducted on the turbine blade, including the groove, to comprehensively understand its behavior under various conditions.

Indal Singh [6]: To enhance the thermal performance of thermal systems and facilitate faster heat transfer, it's standard practice to implement methods that boost heat transmission. Utilizing turbulators is a common

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approach, which involves inserting various types of devices into duct flow. These turbulators disrupt the formation of thermal boundary layers, enlarge the heat transfer surface area, and enhance heat transfer by intensifying turbulence or promoting fluid mixing at a higher rate.

Aihua Dong [7]: This paper presents a study where composite inner cooling structures within the rotating blade of a first-stage heavy gas turbine were modeled and simulated using coupled heat transfer (CHT) techniques. Flow characteristics and heat transfer performance were analyzed comparatively under both stationary and rotational conditions. Findings indicate notable increases in turbulence intensity, flow resistance, and heat transfer levels within the rotating coolant compared to stationary conditions. These enhancements are attributed to the combined influence of Coriolis force, centrifugal force, and associated buoyancy forces.

William Wiberg [8]: The objective of the thesis was to create a novel rotor blade tailored for the KTH test turbine, aligning with the current design standards adhered to by Siemens Industrial Turbomachinery in Finspång for gas turbine manufacturing. Drawing inspiration from stage one of an actual gas turbine, the aerodynamic design served as a foundational blueprint for the project. By maintaining comparable gas conditions, the new rotor blade underwent optimization, focusing on optimizing metal angles and pitch/chord ratio at the reference scale.

J. Turbomach [9]: Ensuring effective cooling of both internal and external airfoils is essential for prolonging the lifespan of components in efficient gas turbines. Cooling strategies have evolved from basic internal convective channels to sophisticated designs incorporating double-walls with intricately shaped film-cooling holes. This paper outlines the evolution of an innovative internal and external cooling approach for a modern, cooled turbine blade. Drawing insights from extensive literature reviews, patent analyses, and consultations with academic and industry experts in turbine cooling, these cooling concepts have been refined to enhance turbine performance and durability.

Georgios Karadimas [10]: Turbines are pivotal in converting thermal energy into mechanical work. Traditionally, nickel superalloys have been the go-to choice for turbine blades. However, this paper explores five ceramic matrix composite materials as potential alternatives. Through Finite Element Analysis, the structural and thermal properties of the first stage of a rotor blade gas turbine are scrutinized in this study. The analysis includes assessing thermal behavior and mechanical performance under centrifugal, tangential, and axial forces.

A.S.M. Ashique Mahmood [11]: Topic modeling encompasses statistical methods aimed at analyzing the textual content of documents to unveil latent semantic topics or themes. The predominant technique, latent Dirichlet allocation (LDA), operates on the assumption that each document comprises a blend of topics, and each topic constitutes a distribution of words. LDA functions as an unsupervised, generative model, outlining a process for generating documents based on concealed topic structures. Extensions of LDA include dynamic topic models for tracking topic evolution, hierarchical LDA for modeling topic hierarchies, correlated topic models to capture topic relationships, and author-topic models associating topics with authors. With applications spanning various fields, such as healthcare risk prediction from clinical notes, drug repositioning using drug labels, gut microbiome sample analysis, activity recognition from sensor data, news correlation with stock markets, and social media text analysis, topic modeling serves as a versatile unsupervised technique for revealing thematic structures within textual datasets.

G. Gilardi [12]: This literature survey provides an overview of impact and contact dynamics modeling approaches, classified into impulse-momentum (discrete) models and continuous force-based models. Discrete models treat impact as an instantaneous event and use coefficients like restitution to account for energy loss. Continuous models explicitly model contact forces as a function of deformation to capture the continuous interaction. The paper reviews different restitution models for discrete approaches and contact force models like spring-dashpot and Hunt-Crossley models for continuous approaches. It also discusses experimental validation of these models and identification of parameters like restitution coefficient, contact stiffness and damping. Overall, continuous force-based models are better suited for complex contact scenarios between flexible bodies, while discrete models are limited by rigid-body assumptions.

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Khaled Teffah [13]: This article presents a modeling and experimental study of a new thermoelectric cooler-thermoelectric generator (TEC-TEG) module. The module consists of a thermoelectric cooler (TEC) connected thermally in series with a thermoelectric generator (TEG), with a copper heatsink attached. The TEC cools its cold side through the Peltier effect when a voltage is applied. The TEG acts as a partial heatsink for the TEC by converting some of the TEC's waste heat into electricity through the See beck effect. Finite element simulations in COMSOL Multiphysics and experiments were conducted to analyze the module's cooling capacity and power generation at different TEC input voltages. The results showed the cold side temperature decreased to 278.63K (simulation) and 287.3K (experiment) at 4V input. The TEG generated up to 0.5V open circuit voltage. This demonstrates the potential for a new cascade thermoelectric module for combined cooling and power generation.

Hristijan Mickoski [14]: This paper presents a dynamic modeling and simulation analysis of a three-member robot manipulator. The manipulator kinematics and kinetics are analyzed using Lagrangian equations and virtual work principle to determine the joint control forces and moments. Equations of motion for each joint are derived analytically. A simulation model of the manipulator is developed in MATLAB/Simulink using joint actuator blocks with defined motion trajectories. External forces are applied and joint sensors measure the reaction forces and moments. The simulation results for control forces and moments match those obtained analytically, validating the simulation model. This method allows determining manipulator joint forces for modeling, design and control system applications. The simulation model provides an effective way to analyse manipulator dynamics.

Ranran Geng [15]: This document presents a study on the mechanical drift phenomenon in linear ultrasonic motors (LUMs). The authors establish a mechanical model to analyze the drift mechanism in a V-shaped LUM with flexible clamping components. They find that asymmetry in the clamps' stiffness causes the stator to tilt and the slider to drift over time. Experiments with clamps of varying stiffness support the analysis. To mitigate drift, the authors propose using a straight beam clamp with high tangential stiffness on one side. Experiments show this largely eliminates drift in the LUM. Overall, the research identifies the cause of mechanical drift in LUMs and provides a modified design to improve positional stability.

Fakada Dabalo [16]: This article explores thermo mechanical modeling and analysis of residual stresses in the wire arc additive manufacturing (WAAM) process. It summarizes recent progress in understanding how thermal cycles during WAAM lead to residual stresses that affect mechanical properties and quality of printed parts. The paper discusses common defects like cracking, distortion, and porosity caused by uneven heating and cooling. It reviews thermal and mechanical finite element modeling approaches used to simulate temperature distributions, residual stresses, and distortions in printed parts. Experimental techniques like neutron diffraction for measuring residual stresses are also covered. Methods for minimizing residual stresses such as optimized process parameters, rolling, heat treatments, and cooling are reviewed. Overall, managing thermal effects through process control and modeling remains critical for improving quality of WAAM printed metal parts.

Eslaw Kwasniewski [17]: This article explores various modeling techniques for assessing building structures' robustness against progressive collapse. Three methods are introduced: the Design-Oriented Method, employing nonlinear static analysis and simplified dynamic assessments; the Detailed Nonlinear Dynamic Analysis, utilizing finite element models for comprehensive dynamic response but facing challenges like numerical convergence and computational demands; and the Applied Element Method, a hybrid approach combining finite and discrete elements for modeling the entire collapse process. While simplified methods offer valuable design insights, detailed analysis methods provide a profound understanding of structural collapse mechanics

Rajarishi Sinha [18]: This paper reviews modeling and simulation methods for the DESIGN AND ANALYSIS OF complex Engineering systems. It focuses on system-level modeling languages and tools that can represent multi-disciplinary systems combining continuous and discrete phenomena. Key aspects discussed include model expressiveness, ease of reuse, integration with design tools, and support for collaborative modeling. The paper compares different modeling paradigms like bond graphs, block diagrams, and linear graphs. It also

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reviews recent advances like equation-based declarative modeling, object-oriented modeling, and component-based modeling. Overall, the paper surveys the state of the art in modeling and simulation for Engineering system design, highlighting remaining challenges and future research needs.

Hanmant [19]: This research by Bhise Sanjay & Hanmant focuses on a liquid spring shock absorber designed for isolating sensitive electronic equipment from shock loads in defense applications. The report discusses design considerations, the adoption of a double-acting shock absorber using silicone oil, and mathematical modeling to describe the shock absorbers behavior. The study aims to simulate and understand the system's responses, ensuring they stay within acceptable limits of displacement, acceleration, and pressure. This work was conducted in 2010 as part of mechanical and industrial Engineering research.

Massimo Carraturo [20]: Accurate prediction of part deflections after removing support structures is crucial for assessing the quality of products made with laser powder bed fusion (LPBF) 3D printing. Typically, finite element analysis is used to estimate how 3D printed parts will distort. LPBF's flexible nature results in complex shapes, making mesh generation from 3D models challenging. Immersed boundary methods are proposed as a solution to simulate the process without complex meshing. The text introduces a numerical framework for thermo-mechanical analysis, which is validated through measurements of part deflection in a single-cantilever structure after support removal. The results show that the proposed numerical framework provides highly accurate predictions, with a maximum relative error below 5%.

Mamidi Thrivendra Kumar N [21]: The paper delves into the design of propeller blades under diverse loading conditions, employing static and dynamic analyses to assess deformation, stress, and strain in a composite aircraft propeller blade. Additionally, fatigue analysis was conducted to predict the component's longevity. Optimization was pursued by varying blade count (2, 3, and 5) and material (E-glass Epoxy, 6061 Aluminum Alloy, and Carbon Epoxy) for the propeller blades. Findings indicated that a 5-blade propeller crafted from carbon epoxy material exhibited the lowest stress levels and highest safety factor, rendering it the optimal choice. 3D modeling was executed using SOLIDWORKS parametric software.

Mikhail Aleshin [22]: This study presents the findings of a structural optimization process applied to propeller blades, focusing on their composite composition and pitch adjustment mechanism. Employing Fluid-Structure Interaction (FSI) methods, the primary optimization criterion was propeller thrust. Parameters for optimization included the internal structure characteristics of the composite propeller blade. The objective was to identify the most efficient configuration of the composite material and its micro-geometric parameters along the blade height to minimize deformations and enhance propeller thrust. This approach facilitated the acquisition of dependable thrust values while reducing computational time. Additionally, the study elucidated the impact of composite material structure on the mechanical properties of the blades.

CONCLUSION

Gas turbine rotor blades operate in a brutal environment - scorching temperatures and high rotational speeds combine to create immense stress. Researchers are constantly innovating to improve blade design and material selection. This includes exploring advanced cooling techniques to manage heat, meticulous selection of materials like nickel superalloys or even exploring composite alternatives, and utilizing sophisticated computer simulations to analyze the complex interplay between thermal and mechanical stresses on the blades. This relentless pursuit of improvement is driven by the goal of creating ever more efficient, durable, and reliable gas turbine rotor blade.

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