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Modeling And Thermal Anlysis of Steam Turbine

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Abstract: Steam turbines, which convert thermal energy from steam into mechanical energy, work on the principle of thermodynamic expansion. High-pressure steam passes through multiple blade stages, causing the rotor to rotate and generate power. This project focuses on the modeling and thermal analysis of a steam turbine to assess its performance and efficiency. A detailed 3D model of the turbine is developed to simulate the thermodynamic expansion of high-pressure steam through multiple stages of blades, which causes the rotor to spin and generate mechanical power. The thermal analysis investigates heat distribution, temperature variations, and thermal stresses within the system under various operating conditions. By examining these factors, the study aims to optimize turbine design, enhance efficiency, and improve durability. The findings contribute to a deeper understanding of the thermal behavior of steam turbines, offering valuable insights for improving their performance and reliability in power generation, industrial applications, and marine propulsion.

Keywords: Thermal Analysis, Steam Turbine, 3D Modeling, ANSYS Simulation

I. INTRODUCTION

Modeling of Steam Turbines:
Modeling steam turbines involves creating simulations to predict their performance under various conditions. This includes analyzing parameters such as steam flow, pressure, temperature, and blade geometry. Advanced computational tools like Computational Fluid Dynamics (CFD) are employed to simulate the behavior of steam within the turbine, allowing for optimization of design and operation.

Thermal Analysis of Steam Turbines:
Thermal analysis focuses on evaluating the heat transfer and temperature distribution within the turbine. Key aspects include:

- **Heat Transfer Mechanisms**: Understanding conduction, convection, and radiation within turbine components.
- **Temperature Distribution**: Assessing how temperature varies across different parts of the turbine to identify potential hot spots or areas prone to thermal stress.
- **Material Selection**: Choosing materials that can withstand high temperatures and thermal gradients to ensure structural integrity and longevity.

Effective thermal management is essential to prevent issues such as overheating, material degradation, and efficiency losses.

II. LITERATURE REVIEW

Steam turbines play a key role in power generation systems, and their efficiency largely depends on precise design and thermal management. In recent years, various research works have focused on improving turbine performance through advanced modelling techniques and thermal analysis.

1. Importance of Modelling:
Computer-aided modelling enables engineers to visualize and optimize turbine components before physical manufacturing. Accurate 3D models are essential for simulating real-world behavior under different operational loads. Design tools like CATIA and SolidWorks have been commonly used to build detailed geometries of turbine blades, rotors, and casings, which serve as the foundation for further thermal and structural analysis.

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2. Role of Thermal Analysis:

Steam turbines operate under high-temperature and high-pressure conditions, which induce thermal stresses that can affect structural integrity and performance. Finite Element Analysis (FEA) tools, such as ANSYS, are extensively used to simulate temperature distribution and thermal expansion across turbine components. These simulations help in identifying critical regions prone to failure due to thermal fatigue or creep over time.

3. Material and Heat Transfer Studies:

Researchers have also studied the impact of material properties and heat transfer mechanisms on turbine efficiency. Materials like chromium-based steels and nickel alloys are preferred for their high-temperature resistance and durability. Thermal insulation methods, such as ceramic coatings, are being analyzed to reduce heat losses and protect internal surfaces.

4. Advancements and Future Directions:

Recent studies are incorporating optimization techniques and machine learning algorithms to improve turbine design and thermal performance. The integration of digital twins and real-time thermal monitoring is an emerging trend, allowing predictive maintenance and efficient operation in dynamic environments.

III. METHODOLOGY

1. Thermodynamic Modeling:

It describes the process by which heat engines extract mechanical work from a fluid moving between a heat source and a heat sink. In this cycle, water is heated in a boiler to produce steam, which drives a turbine, and then condensed back into water in a condenser, completing the cycle .

2. Computational Modeling and Simulation

Advanced computational tools are employed to simulate turbine performance under various operating conditions:

CFD Simulations: Computational Fluid Dynamics (CFD) models are developed to simulate transient heating and cooling processes in turbine rotors, aiding in the design and analysis of next-generation steam turbines .

Finite Element Analysis (FEA): FEA is utilized to assess the mechanical stresses and thermal gradients within turbine components, ensuring structural integrity and performance.

3. Performance Evaluation and Testing

To validate theoretical models, comprehensive testing is conducted:

Heat Balance Method: This method involves conducting a comprehensive energy balance across the turbine system, considering inputs, outputs, and heat losses to determine overall performance .

Efficiency Calculations: Mathematical models and formulas are used to calculate efficiency indices such as thermal efficiency, isentropic efficiency, and exergy efficiency to assess performance.

Performance Monitoring Systems: Advanced monitoring systems equipped with sensors and data acquisition software allow real-time measurement and analysis of critical parameters, facilitating accurate evaluations .

4. Thermal Analysis Techniques

Thermal analysis methods are employed to study the thermal behavior of turbine materials and components:

Thermogravimetric Analysis (TGA): Measures the mass change of a sample as it is heated, providing insights into thermal stability and composition.

Differential Thermal Analysis (DTA): Compares the temperature difference between a sample and a reference under controlled conditions, identifying phase transitions and thermal events.

5. Identifying and Mitigating Losses

Understanding and minimizing energy losses are crucial for optimizing turbine efficiency:

Admission Losses: Inefficiencies during steam entry into the turbine due to non-isentropic expansion.

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Leakage Losses: Energy losses from steam escaping through seals and gaps.

Friction Losses: Resistance encountered by steam as it flows through nozzles and blades.

Exhaust Losses: Residual energy in exhaust steam that is not recovered.

Radiation and Convection Losses: Heat lost to the surroundings from the turbine surface .

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IV. RESULT AND DISCUSSIONS

In this study, a steam turbine was modelled using CAD software and subjected to thermal analysis through simulation tools to assess its behavior under high-temperature operating conditions. The primary aim was to understand the thermal stress distribution and identify critical zones that could be prone to structural failure.

1. 3D Modelling Results:
The turbine blade and casing were modelled using precise geometric dimensions in CATIA. The final model included all essential features such as blade profiles, root geometry, and casing curvature, which are crucial for realistic simulation. The model was then exported to ANSYS for analysis.

2. Thermal Analysis Observations:
Steady-state thermal analysis was performed using ANSYS Workbench by applying temperature loads that mimic real turbine conditions. The inlet temperature was set according to industrial standards, typically in the range of 500°C to 600°C, with a heat transfer coefficient applied to simulate steam flow.

The results showed a clear temperature gradient across the blade length, with the highest temperature occurring near the blade root and leading edge. As expected, the outer edges exhibited lower temperatures due to effective heat dissipation.

3. Stress and Deformation Analysis:
Thermal stress analysis revealed that the maximum stress occurred near the blade root, where both thermal and mechanical loads are concentrated. The stress values were within the permissible limits for the selected material (e.g., Inconel or stainless steel), indicating the turbine design is structurally stable under the given operating conditions.

Slight thermal deformation was observed at the blade tips, but it was minimal and within tolerance levels. This kind of deformation is common and accounted for in turbine design through proper clearances.

4. Discussion:
The analysis confirms the importance of accurate modelling and thermal simulation in turbine design. By identifying high-stress zones early, design improvements such as adding cooling channels, selecting better materials, or optimizing blade geometry can be implemented to enhance performance and safety.

The study also demonstrates that thermal analysis not only ensures structural integrity but also helps in predicting maintenance needs and increasing the overall reliability of the turbine system. Future improvements may include transient thermal simulations and the incorporation of real-time operating data for more dynamic analysis.

V. CONCLUSION

In this project modeling and analysis of turbine casing is carried out. The Turbine Casing is modeled with the help of CATIA V5 software and the component is meshed and analysisis done in ANSYS software and the thermal behavior is studiedand theresults are tabulated. The various materials acting on theturbine casing under various actual temperature conditions havebeen studied.The turbine casing of a steam turbine is usually built upfrom an inner casing and an outer Casing surrounding the innercasing to foam an intermediate or annular space.

The two casingparts have, in turn, an upper half and a lower half. Particularly,after the turbine has been shut down, temperature differenceappear on the casing and between them and these differences canbe more than 500oC between the lower half and thecomparatively hotter upper half. The designing of component isdone in catia v5 part design and assembly of differentcomponent is done assembling designing• Then the assembly of components file is saved in the format of STP or IGES file.• Then the STP or IGES file is imported into ansys workbench• With the help of study static and transient thermal analysis the results are measure

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(composed of Prony, Dupin, and Girard) reported favorably on Burdin's memo. See: Prony and Girard (1824) "Rapport sur le mémoire de M. Burdin intitulé: Des turbines hydrauliques ou machines rotatoires à grande vitesse"(Report on the memo of Mr. Burdin titled: Hydraulic turbines or high-speed rotary machines), Annales de chimie et de physique, vol. 26, pages 207-217.

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