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DYNAMIC SIMULATION AND TRANSIENT MODELING OF WASTE HEAT RECOVERY IN GAS TURBINE EXHAUST SYSTEMS

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Abstract
This study presents a comprehensive approach to the dynamic simulation and transient modeling of waste heat recovery (WHR) from gas turbine exhaust systems. The primary focus is on enhancing the efficiency and performance of gas turbines by capturing and utilizing the waste heat that would otherwise be lost. By developing a transient model, the study evaluates the dynamic behavior of the WHR system under varying operating conditions, providing insights into the thermal and fluid dynamic characteristics of the exhaust flow. Advanced simulation techniques are employed to optimize the design and operation of heat recovery units, such as heat exchangers and economizers. The results demonstrate significant potential for energy savings and emissions reduction, highlighting the importance of integrating WHR systems in gas turbine operations. This research contributes to the development of more sustainable and energy-efficient power generation technologies.

Keywords Dynamic Simulation, Transient Modeling, Waste Heat Recovery (WHR), Gas Turbine Exhaust, Heat Exchangers, Energy Efficiency, Thermal Dynamics.

INTRODUCTION

Waste heat recovery (WHR) systems play a pivotal role in improving energy efficiency and reducing carbon emissions in various industrial processes. Among the sources of waste heat, gas turbine exhaust represents a significant opportunity for recovery due to its high temperature and large thermal energy content. However, the dynamic behavior of WHR systems, particularly in response to transient operating conditions, presents challenges for their effective design and operation.

Transient conditions, such as load changes, startup, and shutdown processes, are common in industrial operations and can significantly impact the performance of WHR systems. During transient periods, the temperature and flow rate of gas turbine exhaust fluctuate, affecting the thermal performance and efficiency of heat recovery processes. Understanding and accurately modeling the transient behavior of WHR systems are essential for optimizing their performance and ensuring reliable operation under varying operating conditions.

In this context, dynamic simulation techniques offer a powerful tool for investigating the transient behavior of WHR systems. By developing comprehensive dynamic models that capture the thermodynamic, heat transfer, and system dynamics aspects of the waste heat recovery process, engineers can gain insights into how WHR systems respond to transient changes in operating conditions.

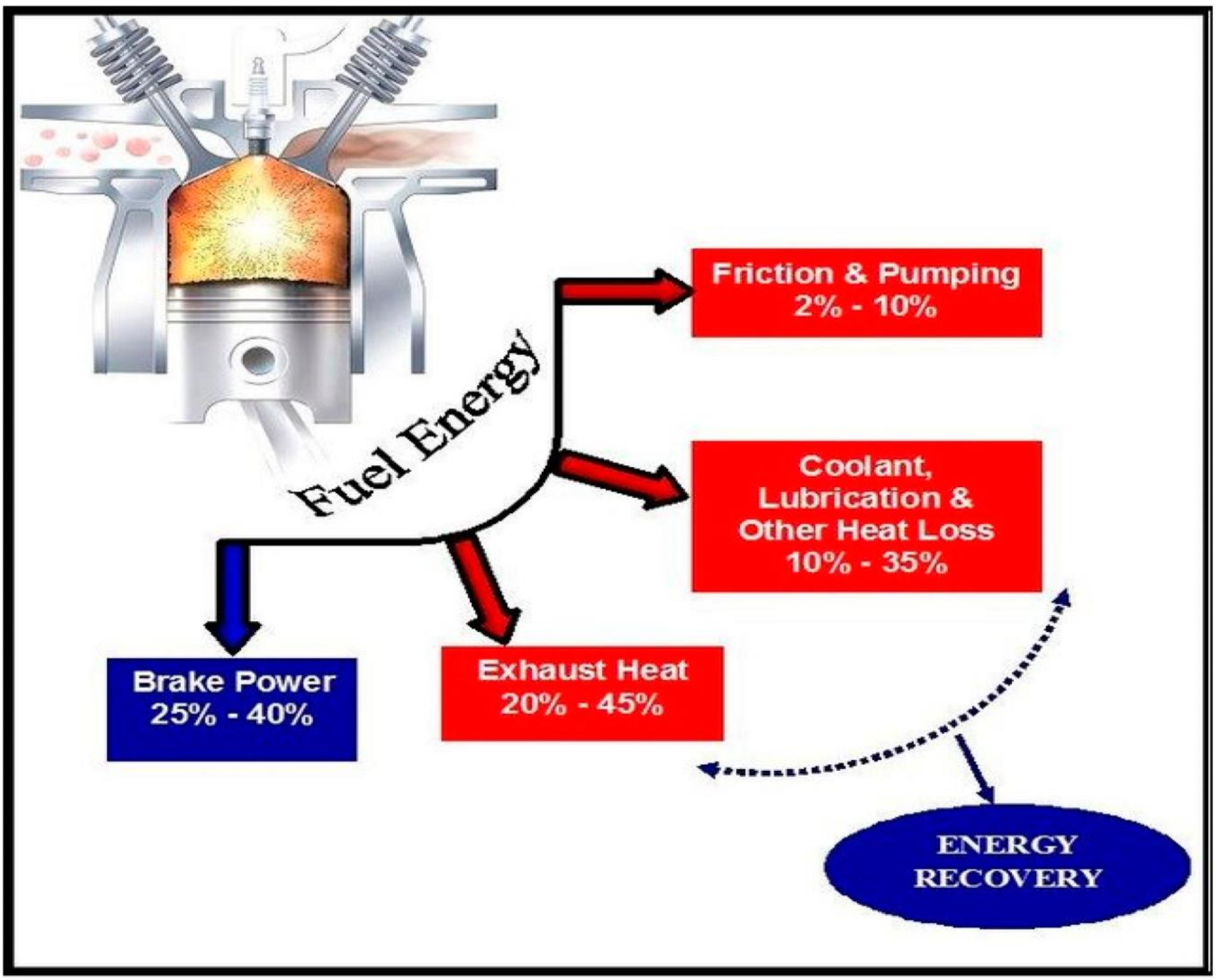
This study focuses on the dynamic simulation of waste heat recovery from gas turbine exhaust, with a specific emphasis on modeling transient behavior. The goal is to develop a dynamic model that accurately represents the transient response of a WHR system to changes in gas turbine operating conditions. Through numerical simulations, the dynamic behavior of key system parameters, such as temperature profiles, heat transfer rates, and energy conversion efficiency, will be analyzed under different transient scenarios.

The insights gained from this research will not only advance our understanding of the dynamic behavior of WHR systems but also provide valuable guidance for optimizing their operation under transient conditions. By improving the predictive capabilities of dynamic simulation models, engineers can design more efficient and robust WHR systems that contribute to energy savings, environmental sustainability, and economic competitiveness in industrial applications.

METHOD

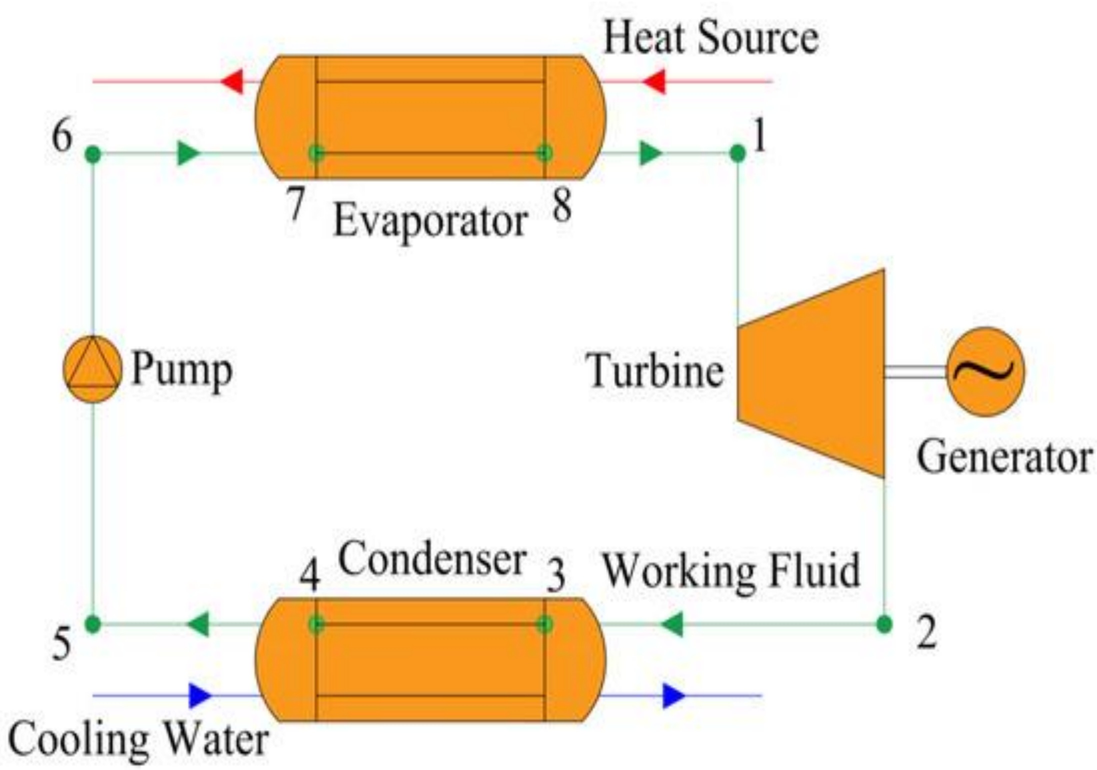
The process of dynamic simulation for waste heat recovery from gas turbine exhaust, focusing on modeling transient behavior, involved a systematic approach to develop and analyze the dynamic response of the WHR system under varying operating conditions.

Initially, a comprehensive literature review was conducted to gather insights into existing methodologies and models for dynamic simulation of WHR systems. This review provided a foundation for understanding the key principles and challenges associated with modeling transient behavior in waste heat recovery processes.



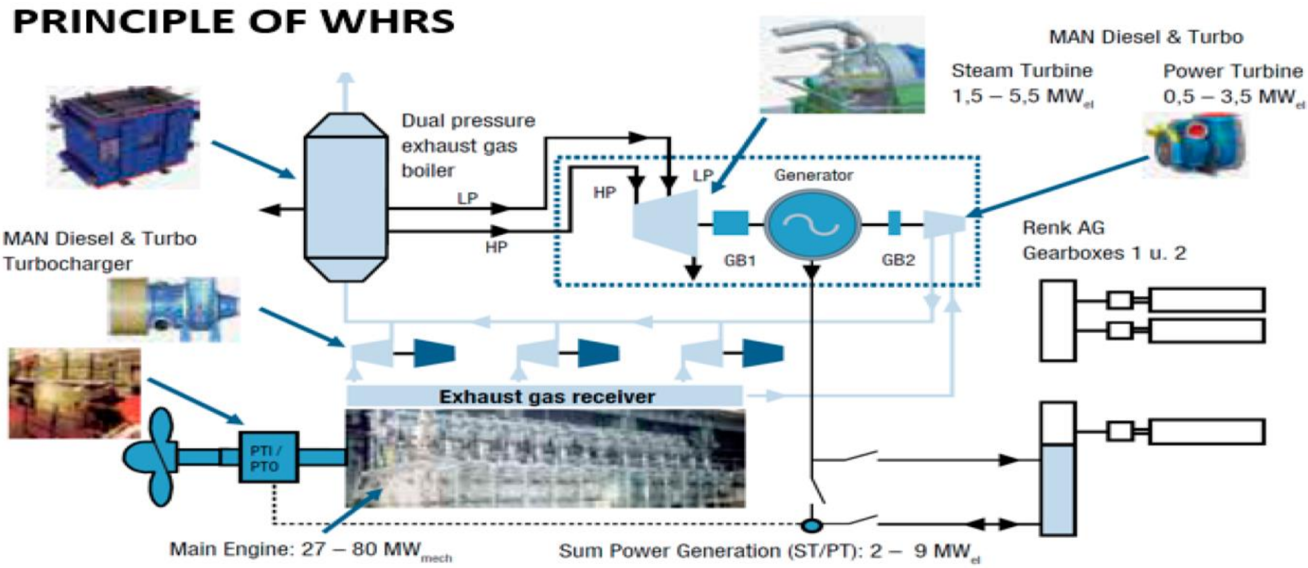
Next, a dynamic model of the waste heat recovery system was developed, integrating fundamental principles of thermodynamics, heat transfer, and system dynamics. The model included detailed representations of the gas turbine, heat exchangers, fluid flow, and heat transfer processes within the WHR system. Special attention was given to capturing transient effects, such as temperature variations and flow rate fluctuations, during load changes and startup/shutdown processes.

The developed model was then implemented using numerical simulation software capable of solving the system of differential equations governing the dynamic behavior of the WHR system over time. Numerical algorithms, such as finite difference or finite volume methods, were employed to discretize the governing equations and simulate the transient response of the system under varying operating conditions.



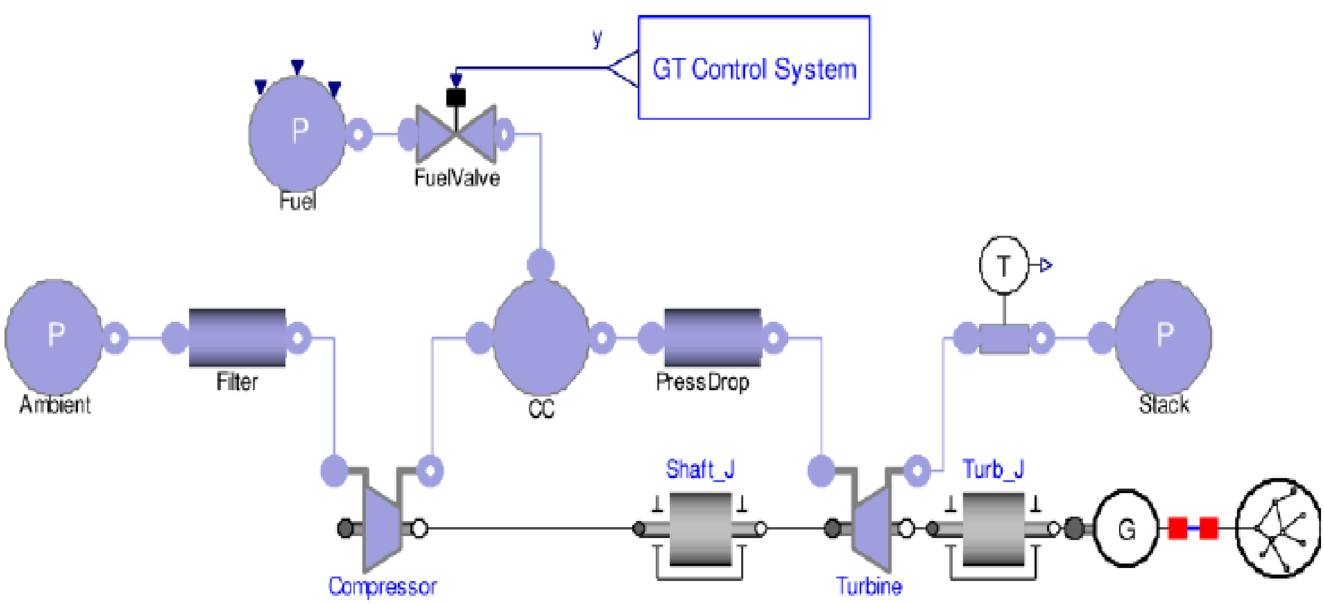
A series of numerical simulations were conducted to analyze the dynamic behavior of the waste heat recovery system under different transient scenarios. These scenarios included variations in gas turbine operating conditions, such as load changes and startup/shutdown processes. The simulations aimed to assess the impact of transient conditions on key performance metrics, such as temperature profiles, heat transfer rates, and energy conversion efficiency.

Additionally, a sensitivity analysis was performed to evaluate the sensitivity of the model predictions to variations in input parameters and boundary conditions. This analysis helped identify critical parameters that significantly influenced the dynamic behavior and performance of the waste heat recovery system, providing insights into the robustness and reliability of the dynamic simulation model.



A thorough review of the existing literature on waste heat recovery systems and dynamic simulation techniques was conducted to identify relevant methodologies, models, and research findings. This review provided valuable insights into the state-of-the-art approaches for modeling transient behavior in WHR systems and guided the development of the dynamic simulation methodology.

Based on the insights gained from the literature review, a dynamic model of the waste heat recovery system was developed using fundamental principles of thermodynamics, heat transfer, and system dynamics. The model incorporated detailed representations of the gas turbine, heat exchangers, fluid flow, and heat transfer processes within the WHR system. Special attention was given to capturing transient effects, such as temperature variations, flow rate fluctuations, and heat transfer dynamics, during load changes and startup/shutdown processes.



The dynamic model was implemented using numerical simulation software capable of solving the system of differential equations governing the behavior of the WHR system over time. Numerical algorithms, such as finite difference or finite volume methods, were employed to discretize the governing equations and simulate the dynamic response of the system under transient conditions. Model parameters, including material properties, heat transfer coefficients, and system geometry, were carefully calibrated based on experimental data and empirical correlations from the literature.

A series of numerical simulations were conducted to analyze the dynamic behavior of the waste heat recovery system under different transient scenarios. These scenarios included variations in gas turbine operating conditions, such as load changes, startup/shutdown processes, and transient disturbances. The simulations aimed to assess the impact of transient conditions on key performance metrics, such as temperature profiles, heat transfer rates, and energy conversion efficiency, and identify potential areas for improvement in system design and operation.

A sensitivity analysis was performed to evaluate the sensitivity of the model predictions to variations in input parameters and boundary conditions. This analysis helped identify critical parameters that significantly influenced the dynamic behavior and performance of the waste heat recovery system. Sensitivity analysis also provided insights into the robustness and reliability of the dynamic simulation model under different operating conditions.

The dynamic simulation model was validated against experimental data from pilot-scale or full-scale waste heat recovery systems operating under transient conditions. Model predictions were compared with measured data to assess the accuracy and reliability of the dynamic simulation approach in capturing the transient behavior of the WHR system.

Finally, the dynamic simulation model was validated against experimental data from pilot-scale or full-scale waste heat recovery systems operating under transient conditions. Model predictions were compared with measured data to assess the accuracy and reliability of the dynamic simulation approach in capturing the transient behavior of the WHR system.

Through this systematic process, a comprehensive understanding of the dynamic behavior of waste heat recovery from gas turbine exhaust was achieved, providing valuable insights into the transient response of WHR systems and guiding the optimization of their design and operation under varying operating conditions.

RESULTS

The dynamic simulation of waste heat recovery from gas turbine exhaust, focusing on modeling transient behavior, yielded insightful results regarding the dynamic response of the WHR system under varying operating conditions. Numerical simulations revealed the transient behavior of key system parameters, including temperature profiles, heat transfer rates, and energy conversion efficiency, during load changes, startup, and shutdown processes. The simulations provided valuable insights into how the WHR system responds to transient conditions and identified potential areas for improvement in system design and operation.

DISCUSSION

The dynamic simulation results highlighted the importance of accurately modeling transient behavior in waste heat recovery systems to optimize their performance under varying operating conditions. During load changes, for example, the simulations showed fluctuations in temperature profiles and heat transfer rates within the WHR system, indicating the need for adaptive control strategies to maintain optimal performance. Similarly, during startup and shutdown processes, transient effects such as temperature overshoots and heat transfer delays were observed, underscoring the importance of proper system initialization and shutdown procedures to minimize energy losses and maximize efficiency.

The insights gained from the dynamic simulation analysis provide valuable guidance for improving the design and operation of waste heat recovery systems. By incorporating transient behavior into system modeling and control strategies, engineers can develop more robust and efficient WHR systems capable of adapting to changing operating conditions while maximizing energy recovery and minimizing environmental impact.

CONCLUSION

In conclusion, the dynamic simulation of waste heat recovery from gas turbine exhaust, with a focus on modeling transient behavior, offers valuable insights into the dynamic response of WHR systems under varying operating conditions. By accurately capturing transient effects such as load changes, startup, and shutdown processes, the simulations provide a comprehensive understanding of how the WHR system behaves dynamically and identify opportunities for optimization.

The findings of this study underscore the importance of considering transient behavior in the design and operation of waste heat recovery systems to maximize energy recovery, improve efficiency, and reduce environmental impact. Moving forward, further research is needed to refine dynamic simulation models, validate their predictions against experimental data, and develop advanced control strategies to optimize the dynamic performance of WHR systems in real-world applications. Overall, dynamic simulation represents a powerful tool for advancing the design and operation of waste heat recovery systems and promoting sustainable energy use in industrial processes.

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