Asia Pacific Science Press

Journal of Advances in Engineering and Technology
ISSN(O):3005-7507
ISSN(P):3005-7493
Vol. 2 No.1 (2025)

Analysis on Intrinsic Vibration Characteristics of Disc-Lobe Coupling System of Marine Gas Turbine

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Abstract: As the core component of the modern ship power system, the vibration characteristics of the rotor system are of great importance to the stability and reliability of the whole power system. With the development of lightweight and thin ship gas turbine, the traditional method of only considering the vibration of the blade under the root fixation is no longer applicable. Therefore, it is important to study the vibration characteristics of the wheel and blades as a coupled system. This paper aims to establish the analysis model of the vibration characteristics of the disc-lobe coupling system of Marine gas turbine, and analyze the influence of temperature and rotation speed on the vibration characteristics of the system. Through finite element analysis and experimental verification, this study provides a theoretical basis for the design and safe operation of ship gas turbine. In the process of analysis, this paper first introduces the theoretical basis of the vibration characteristics of the disk-lobe coupled system, including the vibration theory, finite element analysis method, cyclic symmetric structure algorithm, etc. These theoretical bases provide a scientific basis for the subsequent model building and computational analysis. Then, the calculation model of the disc-lobe coupling system of Marine gas turbine is established, and the cyclic symmetry analysis function and geometric nonlinear analysis function of NASTARN is used. In the model, the rotating centrifugal force and the material parameters vary with temperature are consideredinfluence. In addition, the paper verifies the accuracy of the calculation model, and summarizes the relationship between temperature, rotational speed and the intrinsic vibration characteristics of the disk-lobe coupling system. The calculated results and the measured data are also compared. The error sources of the model are analyzed and the practical significance of the experimental results for the design and operation of ship gas turbine is discussed. The results show that the vibration characteristic analysis model of disc-lobe coupled system considering the influence of temperature and rotation speed can provide theoretical support for the design and safe operation of ship gas turbine, and has an important engineering price for improving the reliability and safety of ship power system

Keywords: Marine gas Turbine; Disc-Blade Coupling System; Inherent Vibration Characteristics; Temperature Influence; Rotation Speed Influence

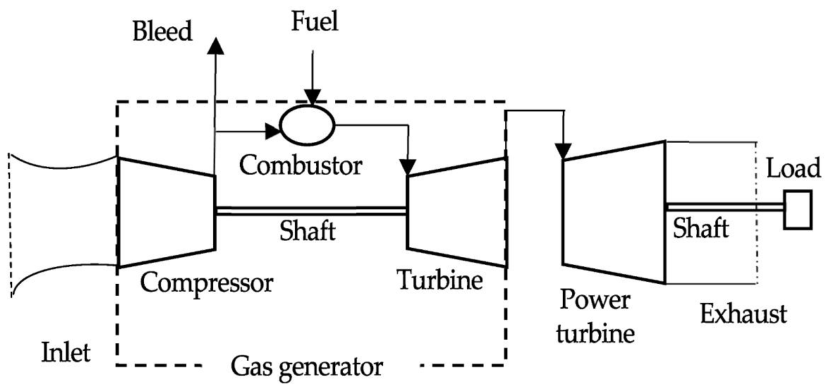
Published: Feb 27, 2025

DOI: https://doi.org/10.62177/jaet.v2i1.174

1.Introduction

The Marine gas turbine is the core component of the modern naval power system, and the vibration characteristics of its rotor system are directly related to the stability and reliability of the whole power system. With the advancement of naval equipment modernization, the ship gas turbine is developing towards the direction of lightweight, thin shape and high efficiency, which requires us to deeply study the coupling vibration characteristics of the wheel and blade, so as to ensure the long-term stable operation of the power system. The development of ship gas turbine has a long history. From the initial imitation and introduction of technology to the current independent research and development and innovation, China has made significant progress in the field of ship gas turbine. Especially after the introduction of UGT-25000 gas turbine, the development of domestic gas turbine technology was greatly promoted through the digestion and absorption of technology. However, with the improvement of the performance requirements of ship gas turbine, the vibration of its rotor system is increasingly prominent, which puts forward higher requirements for the design and operation of gas turbine. Some results have been made in the research of Marine gas turbine. For example, GEs LM2500 series gas turbines, with some parameters as shown in Figure 1, are widely used worldwide due to their high performance and stability. However, these studies have focused on the analysis of the vibration characteristics of individual components and are relatively few for the disc-lobe coupled systems. In addition, most of the existing studies focus on room temperature and pressure, and the vibration characteristics in extreme environments such as high temperature and high pressure are insufficient, which limits the response of ship gas turbines in complex environments

graph 1



2. Analysis of vibration characteristics of disc-lobe coupling system

The vibration characteristic analysis of the disc-lobe coupling system of the Marine gas turbine is crucial to ensure the stability and reliability of the ship power system. In this study, the influence of the centrifugal force and the material parameters with temperature can provide a theoretical basis for the analysis of vibration characteristics.

In terms of theoretical basis, we first understand the centrifugal force of the wheel and the blade in the gas turbine, and the influence of temperature changes on the mechanical properties of the materials. All of these factors can significantly affect the vibrational properties of the system, and therefore the analytical model must be able to simulate these complex physical phenomena. During the operation of the gas turbine, the blades and wheels not only bear the centrifugal force generated by rotation, but also deal with the influence of high temperature gas, which may lead to changes in material properties, thus affecting the vibration response of the whole system.

Building the computational model, we employ finite element analysis to handle complex boundary conditions and nonlinear problems using software such as ANSYS. In particular, the model focuses on the influence of the rotating centrifugal force on the vibrational properties of the disc-lobe coupled system, and on the case where the material parameters vary with temperature. Through the finite element analysis, we can simulate the natural frequency, vibration pattern and fatigue life under different rotational speed and temperature conditions. These analytical results are crucial for understanding the dynamic behavior of the system and provide evidence for subsequent experimental validation and design optimization. Using finite element analysis, we are able to predict the vibration characteristics of the disc-lobe coupling system under different working conditions, including natural frequency, vibration type and fatigue life. These analytical results are crucial for understanding the dynamic behavior of the system and provide evidence for subsequent experimental validation and design optimization. For example, by simulating the vibrational properties at different rotational speeds, we can identify the critical rotational speeds that may lead to the resonance, thus taking steps to avoid or reduce the resonance risks during the design phase.

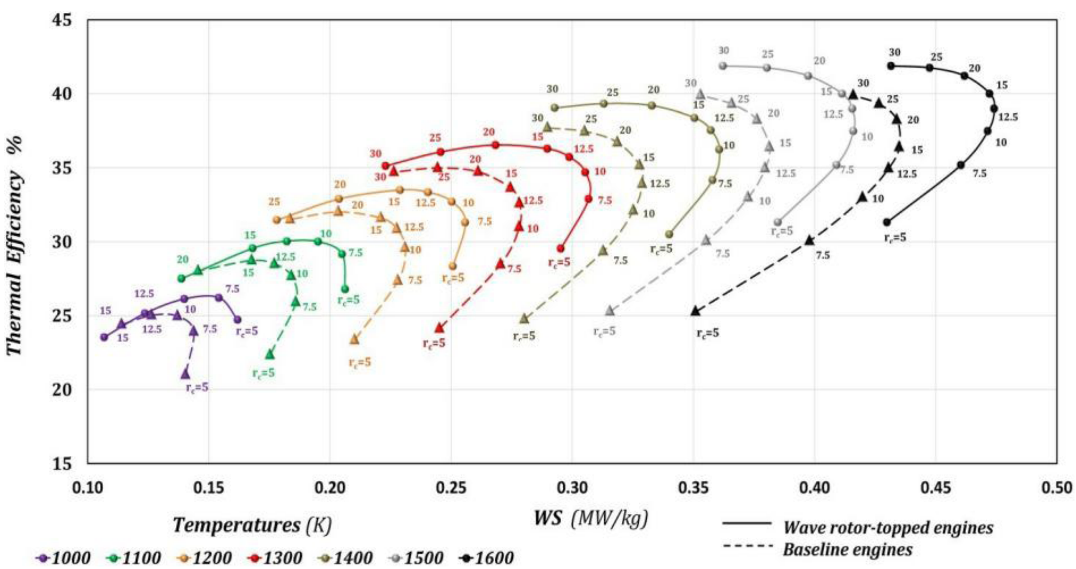
The model comprehensively considers the influence of rotating centrifugal force and material parameters with temperature, and can predict the vibration response of the system under different working conditions. This model not only helps us to have a deep understanding of the dynamic behavior of the disk-lobe coupled system, but also provides important theoretical support for the design and safe operation of ship gas turbines. By simulating the change of material performance in the high temperature environment, we can more accurately predict the performance of gas turbine under the actual working conditions, which is of great significance to improve the reliability of gas turbine and prolong its service life.

The following work will experimentally verify these calculations and further explore the specific effects of temperature and speed on vibration characteristics. Experimental validation will include testing the model in a controlled environment, and data collection under actual gas turbine operating conditions. These experimental results will be compared with the finite element analysis to verify the accuracy of the model and provide guidance for further design optimization. Through this combination of theoretical and experimental methods, we can more fully understand and predict the vibration characteristics of the disc-lobe coupled system, thus providing a solid scientific basis for the design and operation of ship gas turbines.

3.The influence of the temperature and rotational speed on the vibration characteristics

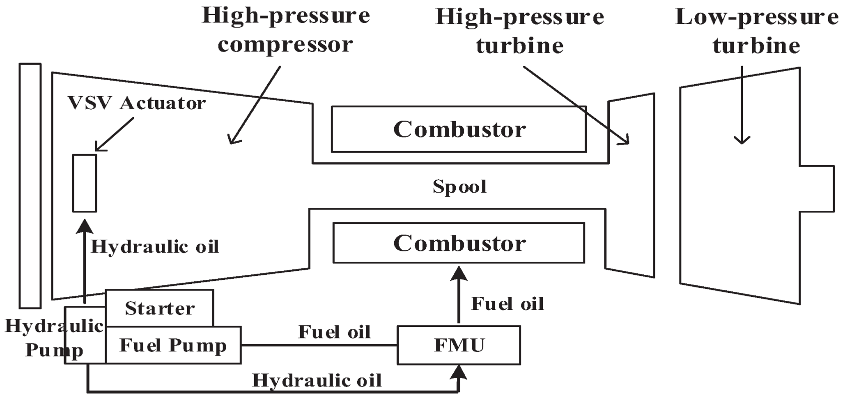
The influence of temperature on the disc-lobe coupled system is multifaceted. First, high temperature environment can change the mechanical properties of materials, such as elastic modulus, yield strength and thermal expansion coefficient. These changes directly affect the natural frequency and damping ratio of the system, and thus affect the vibration properties. For example, as the temperature increases, the elastic modulus of the material may decrease, leading to a decrease in the stiffness of the structure, which in turn reduces the natural frequency of the system, as shown in Figure 2. At the same time, the thermal expansion will cause the geometric size change of the wheel and the blade, which may cause the change of prestress and further affect the vibration characteristics. The change of rotation speed also has an important impact on the vibration characteristics of the disk-lobe coupling system. At different speeds, the size of the centrifugal force will change, which will lead to different stress distribution and deformation of the blade and wheel. In particular, when near or above the critical rotation speed, the system may undergo resonance, resulting in a sharp increase in the vibration amplitude, thus posing a threat to the safety and life of the structure. Therefore, understanding the relationship between rotation speed and vibration characteristics is crucial to avoid resonance and ensure the safe operation of the gas turbine.

graph 2



The disk-lobe coupling system at different temperature and rotational speed was simulated by finite element analysis software. During the simulation, we first built geometric models of the wheel and blades and assigned material properties. We then applied a prestress to the model to simulate the thermal stress and centrifugal force in practical work, as shown in Figure 3. By adjusting the temperature and speed parameters, we calculated the natural frequency, vibration pattern and stress distribution under different conditions.

graph 3



The analysis showed a general decrease in the native frequency and increased amplitude of the disk-lobe coupling system at high temperature. This suggests that the high temperature environment may make the system more prone to resonance and needs to be considered in the design. At the same time, with the increase of the rotation speed, the vibration characteristics of the system will change significantly. Near the critical speed, the vibration response of the system increases sharply, which requires the strict control of the speed in practical operation to avoid the occurrence of resonance. Furthermore, we find that the combined effect of temperature and rotational speed has a complex effect on the vibrational properties of the disk-lobe coupled system. Under some specific combination of temperature and rotational speed, the vibrational characteristics of the system may change nonlinearly. This requires us to consider the effects of temperature and rotational speed in the analysis, but not one of the factors alone.

To further verify the accuracy of the simulation results, we designed a series of experiments. In the experiment, we measured the actual vibration response of the disc-lobe coupled system at different temperature and rotational speed conditions, and compared it with the simulation results. Experimental results show that the simulation results agree well with the experimental data, verifying the effectiveness of our analytical method.

4.Experimental validation and discussion

Experimental validation is a critical step in ensuring the accuracy of the theoretical models and computational analysis. We designed a series of experiments to test the vibration characteristics of the disc-lobe coupled Marine gas turbine system and compared them with the results of the finite element analysis. The experimental setup included the control of the temperature and rotational speed to simulate the actual operating conditions and ensure the reliability and validity of the experimental data.

First, we established an experimental bench that can simulate the working environment of the gas turbine at different speeds and can accurately control the temperature. In the experiment, we used a high-speed dynamic data acquisition system to record the vibration response of the disc-lobe coupled system, including the parameters of displacement, velocity and acceleration. At the same time, we also used a laser oscillometer to measure the vibration amplitude and frequency of the blade to obtain more accurate vibration characteristic data.

During the experiment, we first tested the system at room temperature and recorded the natural frequency and pattern of the system. Subsequently, we gradually increased the temperature to observe the effect of temperature changes on the vibration characteristics. Experimental results show that the natural frequency of the system decreases somewhat and the amplitude increases as the temperature increases, consistent with our finite element analysis. Moreover, the experiment also found that the damping ratio of the system is reduced under high temperature conditions, which may be due to the changes in the material properties.

In terms of speed control, experiments show that the vibration response of the system showed nonlinear changes with increasing speed. In particular, near the critical rotational speed, the vibration amplitude of the system increases dramatically, which agrees with the theoretical predictions. In the experiment, we accurately recorded the critical speed and avoided the resonance by adjusting the speed.

By comparing the experimental data and the finite element analysis results, we find that there is some error between the two. Error sources may include the accuracy of experimental equipment, simulation error of boundary conditions, measurement error of material parameters, and approximate error of numerical calculation. To reduce these errors, we have calibrated the experimental equipment and optimized the meshing and boundary conditions setting for the finite element model. Furthermore, we performed multiple measurements of the material parameters to ensure its accuracy.

The experimental results have great practical significance to the design and operation of ship gas turbine. First, the experiments verify the accuracy of our computational model and provide reliable theoretical support for the design of ship gas turbines. Second, experimental data can help engineers optimize the design of gas turbines, for example, by adjusting the shape of the blades and the material of the wheel, to reduce vibration and avoid resonance. Finally, the experimental results can also be used to guide the operation and maintenance of the gas turbine, for example, by controlling the speed and temperature, to ensure the stable operation of the gas turbine and prolong its service life.

Future studies can further explore the influence of more influencing factors, such as blade installation error and manufacturing defects of the wheel, on vibration characteristics. In addition, other complex factors in the actual operation, such as the starting and shutdown process of the gas turbine, the load change and other effects on the vibration characteristics, can also be considered. Through these studies, we can more fully understand and predict the vibration characteristics of the disc-lobe coupled system, and thus provide more accurate guidance for the design and operation of ship gas turbines.

5.Conclusion and outlook

Through comprehensive theoretical analysis, finite element simulation and experimental verification, the mechanism of temperature and speed on the vibration characteristics of coupled disc-lobe system is revealed, and an analytical model considering these factors is established. First, the study clarifies the effect of temperature on the material parameters and how these changes affect the natural frequency and pattern of the disk-lobe coupled system. The experimental results show that the high temperature environment will lead to the change of the material properties, and then change the vibration characteristics of the system. This finding has important implications for the design of gas turbines that can operate stably at extreme temperatures. In addition, the influence of the changing speed on the vibration characteristics of the system is also confirmed, especially when near the critical speed, the vibration response of the system increases significantly, which is crucial to avoid resonance and ensure the safe operation of the gas turbine.

Through finite element analysis and experimental validation, a reliable analytical model can predict the vibration response of the disc-lobe coupling system under different working conditions. This model not only improves our understanding of the dynamic behavior of coupled disk-lobe systems, but also provides a powerful tool for the design and optimization of ship gas turbines. By adjusting design parameters, such as blade shape, disc material and structure, vibration can be effectively reduced and the performance and reliability of gas turbine can be improved.

The potential direction of future research is, first, to consider incorporating more practical operating conditions into the model, such as the start and shutdown process of gas turbine, load change, etc. These conditions may have effects on the vibrational properties of the disc-lobe coupled system, and further studies is needed to explore the mechanism of influence. Secondly, new materials and manufacturing technologies can be explored to improve the performance of gas turbines at high temperatures and high speeds. For example, superalloys and additive manufacturing technologies may provide new solutions to the challenges in extreme environments. In addition, the development of intelligent monitoring and health management systems is also an important research direction. By monitoring the vibration characteristics of gas turbines in real time, potential faults can be predicted and diagnosed, thus realizing preventive maintenance, reducing downtime, and improving the availability and economy of gas turbines. The combination of machine learning and artificial intelligence technology can further improve the accuracy and efficiency of the monitoring system. Finally, environmental factors and sustainability considerations should also be included in the scope of future research. With the increasing requirements for environmental protection and energy efficiency, studying how to reduce the emission and energy consumption of gas turbines while ensuring performance will be an important direction of future research.

Funding

no

Conflict of Interests

The author(s)declare(s) that there is no conflict of interest regarding the publication of this paper.

References

[1] Luan J ,Cao Y ,Ao R , et al.An overhaul cycle performance degradation modeling method for arine gas turbines.[J].ISA transactions,2024,

[2] Serbin S ,Washchilenko N ,Zhao X , et al.Thermodynamic investigation of the efficiency of ammonia-powered marine solid oxide fuel cells with gas turbine[J].Heliyon,2024,10(20):e39645-e39645.

[3] Yang H L ,Sun Y ,Yang B Z , et al.Coupling vibration mechanism of rotating shaft–disc–blade system with blade crack—A systematical investigation on the effect of crack, condition, and structure parameters[J].Thin-Walled Structures,2024,205(PB):112398-112398.

[4] Deng Z ,Wang Z ,Chen X , et al.Investigation of resistance performance of anti-icing wave-plate separators for marine gas turbines intake system[J].Journal of Physics: Conference Series,2024,2782(1):

[5] Rohit S ,Avdhesh T ,SS R , et al.Thermodynamics of CMC bladed marine gas turbine-LM 2500: Effect of cycle operating parameters[J].International Journal of Engine Research,2023,24(11):4449-4458.

[6] Laihao Y ,Zhu M ,Xuefeng C , et al.Dynamic coupling vibration of rotating shaft–disc–blade system — Modeling, mechanism analysis and numerical study[J].Mechanism and Machine Theory,2022,167

[7] Yang L ,Mao Z ,Wu S , et al.Steady-state coupling vibration analysis of shaft–disk–blade system with blade crack[J].Nonlinear Dynamics,2021,105(1):1-38.

[8] Liu Chao, Li Fanchun, Du Tao. Study on the inherent vibration characteristics of the disc-lobe coupling system for Marine gas turbine [J]. Ship Mechanics, 2016,20 (07): 874-883.

[9] Zhang Yuan, Xin Qingwei, Yu Dazhao. Vibration characteristics analysis of gas turbine disc / blade coupling system [J]. Journal of the Naval Academy of Aeronautical Engineering, 2012,27 (01): 61-65.

[10] Dzida M ,Olszewski W .Comparing combined gas tubrine/steam turbine and marine low speed piston engine/steam turbine systems in naval applications[J].Polish Maritime Research,2011,18(4):43-48.

[11] Wang Wenliang, Zhang Jin, Chen Xiangjun. Inherent mode analysis of disk-lobe coupling systems —— mode synthesis of symmetric structures on the CN group [J]. Journal of Solid Mechanics, 1988, (01): 15-23.1988.01.002.