Dynamic Analysis of Rotor Stability by Investigating Mass and Speed Variations for Enhanced System Stability

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Abstract:
A rotor system supported by a scaffold refers to a rotating shaft or assembly mounted on flexible support structures, such as frames, towers, or platforms. These support structures can significantly influence the dynamic behavior and stability of the rotor. Proper modeling and analysis of such systems are crucial for ensuring safe and reliable operation. The key aspects involved in studying and modeling a rotor-scaffold system experimentally include Rotor modeling, Support structure modeling, Rotor-support coupling, Experimental validation, Nonlinear effects. The accurate modeling and experimental validation of rotor-scaffold systems are essential for various applications, such as rotating machinery in offshore platforms, wind turbines, aerospace structures, and other flexible support structures. Proper understanding and prediction of the coupled dynamics can help avoid resonance, ensure stability, and optimize the design and operation of these systems

Keywords: *Rotating shaft, support structures, rotor-scaffold system etc.*

I. INTRODUCTION

The term "rotor supported by scaffold" usually describes a wind turbine's rotor that is installed, maintained, or repaired while being supported by a scaffold. The spinning part of a wind turbine, known as the rotor, is made up of blades fastened to a central hub. The rotor rotates in response to wind pushing against the blades, turning on the generator and generating energy. Wind turbine rotors are frequently supported by scaffolding during installation or maintenance procedures to allow access for personnel and tools. When doing activities like installation, inspection, repair, or replacement, this scaffolding makes it safer for specialists to access the rotor blades and hub. Technicians may operate at heights on a stable platform thanks to scaffolding, which also guarantees that safety precautions are taken to avoid mishaps or injuries. Additionally, it makes it simpler to transfer the instruments and machinery required for maintaining the wind turbine rotor. In order to guarantee the effectiveness, safety, and structural integrity of the scaffolding systems that support wind turbine rotors, rotor modelling, Support structure modeling, and Rotor-support coupling are essential. Engineers can use it to plan access routes, evaluate and optimize scaffold designs, and simulate different situations in order to reduce hazards and guarantee the installation, upkeep, and successful operation of wind turbines. Studying and modeling a rotor supported by a scaffold through experimentation involves analyzing the dynamic behavior of the rotor system to understand its response and performance characteristics [11]. Fig. 1 shows a typical rotor assembly system with coordinate systems.

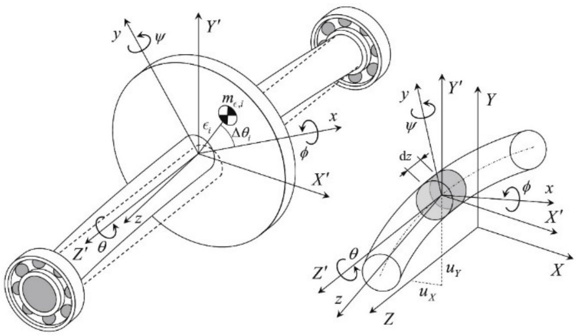


Fig. 1. Rotor assembly and coordinate systems. *[10,25]*

Experimental setups typically involve physical tests on a rotor system to measure parameters such as vibration, displacement, and forces acting on the rotor under different conditions. These experiments provide valuable data for validating theoretical models and improving the design of rotors supported by scaffolds One common approach in experimental rotor studies is to use a test rig with various support systems like bearings or scaffolds to simulate real-world operating conditions. For example, a scaffold can be designed to support the rotor while allowing specific movements and constraints to be evaluated. By subjecting the rotor to different speeds, loads, and operating conditions, researchers can gather data on the performance and stability of the rotor-scaffold system [12]. Researchers use the experimental data collected from these tests to develop mathematical models that describe the rotor's dynamic behavior when supported by a scaffold. These models can include parameters such as mass distribution, stiffness, damping, and the interaction between the rotor and the scaffold. By incorporating experimental results into these models, engineers can better predict how the rotor will behave in various scenarios and optimize its design for improved performance and reliability.

II. Literature Review

The paper discusses the importance of considering the mechanical interactions between the main bearing, gearbox, and structural components in a rotor bearing support system. It highlights the significance of nonlinear effects such as clearance and stiffness characteristics of various components, as well as the influence of assembly process and gravity loads on force transmission. The analysis of these mechanical phenomena through simulation models helps in understanding the system and enables further development and improvement. The paper presents a detailed analysis of the mechanical interactions between the main bearing, gearbox, and structural components in a rotor bearing support system. It highlights the significance of nonlinear effects, such as clearance and stiffness characteristics of various components, and their impact on force transmission. The study emphasizes the importance of using validated modeling techniques to accurately simulate the mechanical phenomena in the system. The analysis of the system through simulation models helps in understanding the force transmission and enables further development and improvement. The paper also discusses the need for realistic modeling of the rotor bearing support system and concepts for monitoring its operating conditions and rotor input loads. The simulation models used in the study are validated by comparing the displacements observed on the test bench with those predicted by the model. The results of the measurement and simulation campaign are presented, including a comparison between the finite-element model and the real system. The paper utilizes a combination of experimental analysis on a system test bench and simulation modeling to investigate the force transmission in a rotor bearing support system. The experimental analysis involves testing the mechanical interactions between the main bearing, gearbox, and structural components of the system. The simulation models are developed using validated modeling techniques to accurately represent the mechanical phenomena and force transmission in the system. Quasi-static loads are applied to the rotor flange in both the test bench and simulation, and the displacements are compared to improve and validate the model. The simulation models are used to analyze the internal loads of different paths and understand the effects observed in the test bench. The mechanical components of a rotor bearing support system cannot be designed and evaluated independently; their combination determines how external loads are transmitted into the tower. Simulation models need to consider nonlinear effects, such as clearance and stiffness characteristics of the main bearing, planet carrier bearings, and clamping bushings, to accurately analyze force transmission. The assembly process of the drivetrain and gravity loads also influence component movement and force transmission. Validated modeling techniques are crucial for reliable simulation models and a realistic investigation of force transmission between the hub and the tower. The analysis of mechanical phenomena through simulation models promotes system understanding and facilitates further development and improvement. The paper emphasizes the importance of considering the complex interactions between mechanical, electrical, aerodynamic, and control components in a rotor support system. [4]

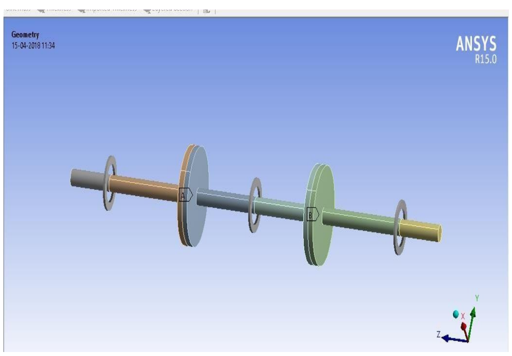
The paper presents a theoretical and experimental investigation of the dynamical behavior of a complex configuration of rotor discs. The theoretical model uses the Galerkin Method to analyze an elastic shaft carrying multiple discs supported by journal bearings. The effects of dynamical forces and moments from the bearings, discs, and shaft are considered. The validity and convergence of the analysis are verified by comparing with Finite Element solutions. The experimental investigation focuses on the forward and backward whirl of a two-disc rotor, showing reasonable agreement with the theoretical results. The paper also explores the effects of geometry, disc sizes, location, and arrangement on the unbalance response and natural frequencies of a three-disc rotor. The Galerkin Method was successfully applied to analyze the dynamical behavior of a complex configuration of rotor discs, with good agreement between the theoretical and Finite Element solutions. The experimental investigation of a two-disc rotor showed reasonable agreement with the theoretical results, with a maximum error of 11%. The effects of geometry, disc sizes, location, and arrangement on the unbalance response and natural frequencies of a three-disc rotor were further investigated. The convergence test indicated that using a small number of modes (not more than 6) was sufficient for accurate analysis. The paper provides valuable insights into the behavior of complex rotor configurations and offers a theoretical and experimental framework for their analysis and design. The paper presents a theoretical model using the Galerkin Method to analyze the dynamical behavior of a complex configuration of rotor discs, considering the effects of dynamical forces and moments from the bearings, discs, and shaft. The validity and convergence of the analysis are verified by comparing with Finite Element solutions, ensuring the accuracy of the proposed method. The experimental investigation of a two-disc rotor provides empirical evidence that supports the theoretical results, demonstrating the practical applicability of the proposed analysis. The paper explores the effects of various factors such as geometry, disc sizes, location, and arrangement on the unbalance response and natural frequencies of a three-disc rotor, providing insights for rotor design and optimization. The convergence test suggests that using a small number of modes (not more than 6) is sufficient for accurate analysis, offering a practical guideline for future studies. [7]

The paper investigates the modeling and performance of a rotor system with a combination of bronze bushing and active magnetic bearing (AMB) as bearing supports. Two different methods, an approximate analytical approach and finite element analysis (FEA), are used to model the system. The controllers for both models are designed using a cost function minimizing AMB controller design method. Experimental tests are conducted on a test rig with AMB suspension and steady state orbits are measured at various speeds. The experimental results are compared to numerical simulations, and recommendations are made regarding the utilization of these dissimilar bearing supports. The paper utilizes two different methods for modeling the rotor system with dissimilar bearing support: an approximate analytical approach and finite element analysis (FEA). A cost function minimizing active magnetic bearing (AMB) controller design method is used for both system models. Experimental tests are conducted on a test rig with AMB suspension, and steady state orbits are measured at several selected constant speeds. The experimental results are compared to numerical simulations to evaluate the performance of the system. Recommendations are made based on the findings regarding the utilization of dissimilar bearing supports. The paper presents the modeling and performance analysis of a rotor system with a combination of bronze bushing and active magnetic bearing (AMB) as bearing supports. Two different methods, an approximate analytical approach and finite element analysis (FEA), are used to model the system. Controllers for both models are designed using a cost function minimizing AMB controller design method. Experimental tests are conducted on a test rig with AMB suspension, and steady state orbits are measured at various speeds. The experimental results are compared to numerical simulations, and recommendations are made regarding the utilization of these dissimilar bearing supports. The paper successfully models a rotor system with dissimilar bearing supports, specifically a combination of bronze bushing and active magnetic bearing (AMB). Two different methods, an approximate analytical approach and finite element analysis (FEA), are used for modeling the system. Controllers for both models are designed using a cost function minimizing AMB controller design method. Experimental tests on a test rig with AMB suspension validate the performance of the system. The experimental results are compared to numerical simulations, providing insights into the utilization of dissimilar bearing supports. [8]

The paper provides a review of the history of rotor balancing research and techniques to avoid balancing problems caused and their consequences on the system. It discusses various methods, including conventional software, influence coefficient & no phase and frequency response methods, which is used to balance rotors in both site and factory settings. The paper reviews the history of rotor balancing research and techniques, including influence coefficient, conventional software, no phase, and frequency response methods to balance rotors. It discusses the theory used in computational algorithms related to the Eigen system Realization Algorithm (ERA) and its application to develop Frequency Response Functions (FRF). The paper also mentions the research conducted by Juang et al. to enhance the application of ERA and minimize noise effects on rotor balancing [2]. Additionally, Pappa et al. studied indicators to assess the consistency of modal parameters identified with ERA, and other researchers investigated and compared the effectiveness of different modal identification algorithms. The paper includes techniques for two-plane balancing using phase information, graphical methods for solving unbalance on a disc using phase information, and solutions for single-plane and multi-plane balancing using only phase information. It highlights the deficiencies of balancing techniques that use only partial information, such as the inability to use residual data for trim balancing and limitations in future efforts. The paper provides a comprehensive review of rotor balancing techniques, including influence coefficient, conventional software, no phase, and frequency response methods. It discusses the theory used in computational algorithms related to the Eigen system Realization Algorithm (ERA) and its application to develop Frequency Response Functions (FRF). The paper highlights the limitations and deficiencies of balancing techniques that use only partial information, such as the inability to use residual data for trim balancing and limitations in future efforts. It also mentions the research conducted by Juang et al. to enhance the application of ERA and minimize noise effects on rotor balancing. The paper includes techniques for two-plane balancing using phase information, graphical methods for solving unbalance on a disc using phase information, and solutions for single-plane and multi-plane balancing using only phase information. Overall, the paper provides a comprehensive overview of rotor balancing techniques and their applications, highlighting the importance of considering various factors and limitations in achieving effective rotor balancing. The paper provides a comprehensive review of rotor balancing techniques, including influence coefficient, conventional software, no phase, and frequency response methods. The use of computational algorithms, such as the Eigen system Realization Algorithm (ERA), can enhance the accuracy and effectiveness of rotor balancing. Balancing techniques that incorporate phase information can be used for two-plane balancing, solving unbalance on a disc, and single-plane and multi-plane balancing. The paper highlights the limitations of balancing techniques that use only partial information, such as the inability to use residual data for trim balancing. Future efforts in rotor balancing should consider these limitations and explore new approaches to improve the effectiveness of balancing techniques. [9]

III. Principle for model design

Principally the model utilized incorporates the assembly with a unit comprising of a simply support structure with two bearings, the rotor mass is a single unit. But the modified model intends to uniformly distribute mass in two sections. Supported by three bearings yielding a very efficient & balanced unit optimizing the unit. The shaft defection in the earlier model is a unit with mass concentrated at a particular location, usually compensated by a higher shaft diameter & bearing size leading to higher costs of the model. The proposed model due to the intermediate support bearing will for sure give a better support reducing the defection and also uniformly distribute the mass and optimize the entire the assembly. In the model there are two rotors with mass m/2, this is redesigned in order to improve the efficiency of the system. The



rotor is mounted on the shaft with three bearings where in dynamic characteristics of the system vary.

Figure 1: Bearing supported rotor.

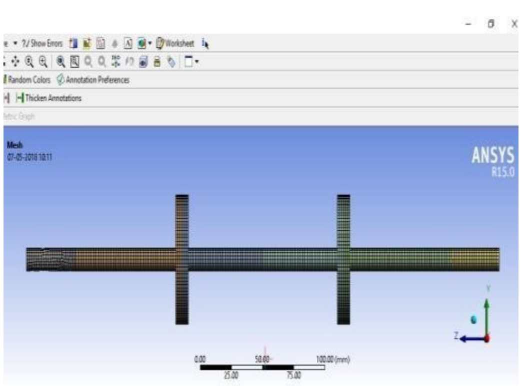
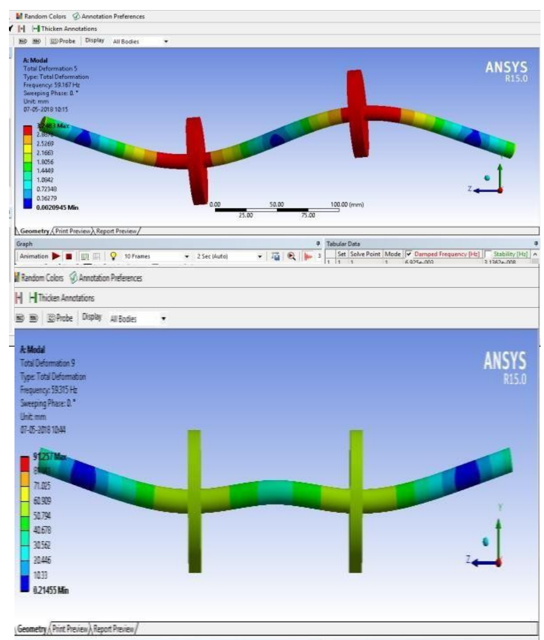


Figure 2: Meshing image

Table 1 : Design setup showing details.

Description	Values
Force	280N
Distance between the bearings.	70mm
Length of the shaft	1200mm
Thickness of the rotor	10mm
Speed of the rotor	Up to 3000 rpm
Stiffness	10^6 N/mm
Mass of the rotor	25 kg and 30kg
Diameter of the rotor	70mm

Figure 3: Mode shape at variable rpm values.



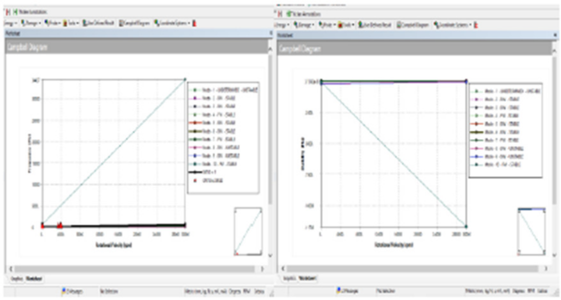


Figure 4: Results obtained showing the stability and critical speed of the system.

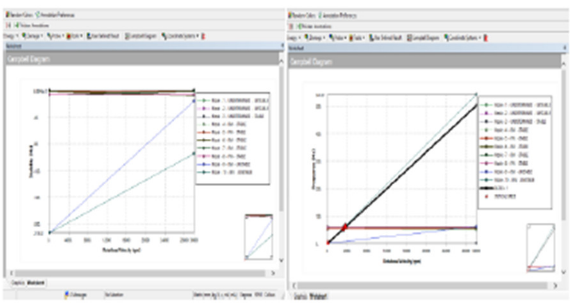


Figure 5: Shows graph for stability at rpm which also shows the critical speed

IV. Results

It is evident from the preceding graph that the system's stability is linear, meaning that the gap changes linearly as system speed rises from 0 to 4000 rpm. As speed rises, the value of the system's stability rises as well. When a rotor has a mass of 25 kg, the critical speed is 3800 rpm; when it has a mass of 30 kg, it is 3400 rpm. The critical speed is the position at where stability and speed transect. We can observe from the graph above that the system's logarithmic decline is linear.

V. Conclusions

From the research, experimentations and literature review stability of the system depends on the mass and speed of the rotor. Hence the mass of the disc is varied and then the stability of the system changes at different masses of the disc rotating at a specific rpm. Dynamic characters like force and stiffness are studied at different rpm. The results obtained in ansys and Bond graph vary about 10%.The simulation time required for ansys is more when compared to Bond graph.

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