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CONTROL OF TRANSVERSE VIBRATIONS IN VERTICALLY INSTALLED ROTATING SHAFTS THROUGH ACTIVE BEARINGS

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ABSTRACT

Machines with vertical shafts, such as generators and electric motors, must address vibration-induced noise and heat. Vertical hydroelectric generators, in particular, are prone to vibrations from water flow and component imbalances, leading to reduced efficiency, early wear, and potential system failure. Controlling shaft vibrations is essential for maintenance and stable operation. This study aims to address these issues by applying active control technology to reduce vibrations in vertical shafts, utilizing active bearings and the NLMS algorithm. To validate the study, simulations were conducted using MATLAB/SIMULINK, and the system was mathematically modeled using the FEM approach. Experiments were conducted at 600 RPM, inspired by the rotational speed of the Porjus U9 generator, and additional analysis was performed across a speed range from 100 RPM to 800 RPM to compare shaft displacement orbits with simulation results. Through this comparison, the reliability of the simulation model was evaluated, and the effectiveness of active control in reducing vibrations was successfully demonstrated. These results suggest that active bearings have the potential to resolve vibration issues in machines with vertical shafts, such as generators and electric motors, thereby extending their operational lifespan.

Keywords: active bearing, finite element method, normalized least mean square algorithm, vertically driven shaft, transverse vibration.

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1. INTRODUCTION

Machines equipped with vertically oriented shafts such as hydroelectric generators and electric motors are frequently subject to vibration-related challenges. In particular, vertical hydroelectric generators experience significant transverse vibrations due to water flow disturbances and internal imbalances in components. These vibrations can result in increased noise, heat generation, mechanical wear, and, ultimately, a decrease in system efficiency and reliability. Over time, excessive vibrations may lead to premature failure of critical components, posing serious maintenance and operational risks. Among the various solutions proposed to mitigate these problems, active vibration control technology has emerged as a promising approach. In contrast to passive methods, active control strategies can adapt to varying operational conditions and effectively suppress unwanted vibrations in real time. This study focuses on applying such a method specifically, the use of active bearings combined with the Normalized Least Mean Square (NLMS) algorithm to control transverse vibrations in vertically installed rotating shafts. To evaluate the proposed method, a mathematical model of the system was developed using the Finite Element Method (FEM), and simulations were conducted using MATLAB and SIMULINK environments. The system behavior was analyzed under a rotational speed of 600 RPM, chosen based on the operational characteristics of the Porjus U9 hydroelectric generator. Additionally, a parametric analysis was carried out across a range of speeds (100–800 RPM) to assess vibration responses and compare shaft displacement orbits with simulation results. Through this analysis, the accuracy and reliability of the proposed model were validated, and the effectiveness of the active control strategy was confirmed. The findings of this research highlight the potential of active bearings as a viable solution for reducing vibrations in vertical shaft systems. This approach not only contributes to the enhancement of machine performance but also extends the operational lifespan of equipment such as generators and electric motors.

2. MODELLING OF ROTOR

In this chapter, we employed the FEM(Finite Element Method) to construct a model of a vertical shaft system comprising a generator and a turbine. The model comprises 15 nodes and 14 elements. Figure 1 below provides a visual representation of this model.

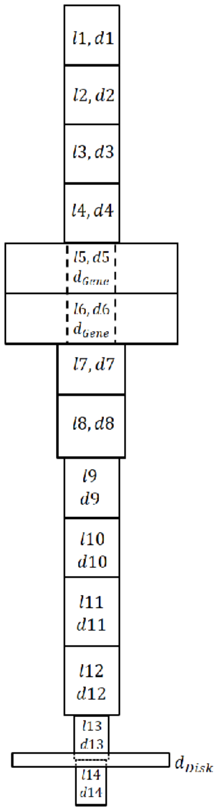

Figure 1. Porjus U9 rotor finite element model.

2.1 Finite element method

For modeling using the finite element method, the shaft model was structured with 14 elements and 15 nodes. The matrices utilized for modeling include the mass, stiffness, and damping matrices. These matrices are detailed as follows.

$$M_i^e = \frac{\rho A_i l_i}{420}\begin{bmatrix} 156 + (\frac{m_d}{\rho A_i l_i/420}) & & & sym \\ 22l_i & 4l_i^2 + (\frac{I_d}{\rho A_i l_i/420}) & & \\ 54 & 13l_i & 156 & \\ -13l_i & -3l_i^2 & -22l_i & 4l_i^2 \end{bmatrix} \quad (1)$$

$$K_i^e = \frac{2EI_i}{l_i^3}\begin{bmatrix} 6 + (\frac{k_i}{2EI_i/l_i^3}) & & & sym \\ 3l_i & 2l_i^2 & & \\ -6 & -3l_i & 6 & \\ 3l_i & l_i^2 & -3l_i & 2l_i^2 \end{bmatrix} \quad (2)$$

$$G_i^e = \begin{bmatrix} 0 & & & sym \\ 0 & I_p\Omega & & \\ 0 & 0 & 0 & \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (3)$$

2.2 Modelling of active bearing

The active bearing system comprises a rubber grommet and a piezo actuator, illustrated in Figure 2. The modeling process involved utilizing linearized stiffness, with the damping effects from oil films in the bearings disregarded. Furthermore, considering the significant rigidity of the housing, it was treated as a rigid body. In Figure 1, the upper bearing of the turbine has been replaced with an active bearing.

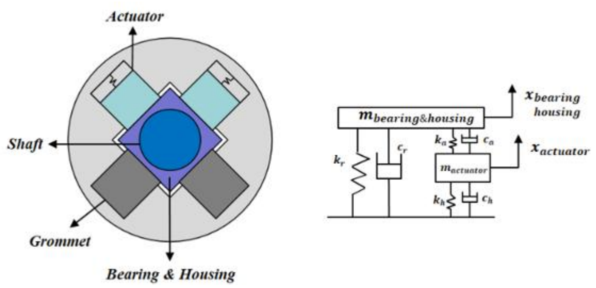

Figure 2. Structure and dynamic model of the active bearing

$m_{bearing\&hosing}$ refers to the mass of the housing attached to the rotor. k_r , c_r express the stiffness and damping of the rubber grommet. Also, $m_{actuator}$ represents the actuator mass. k_a and k_h represent the stiffness of the actuator and the spring located below the actuator, respectively, and c_a and c_h also represent the damping of the actuator and the spring located below the actuator. $x_{bearinghosing}$ and $x_{actuator}$ mean the displacement of the bearing housing and the actuator, respectively.

3. SIMULATION RESULTS

In this study, simulations were conducted at the nominal speed of 600 rpm. The overall system response obtained from the simulation-based control is presented in Figure 3.

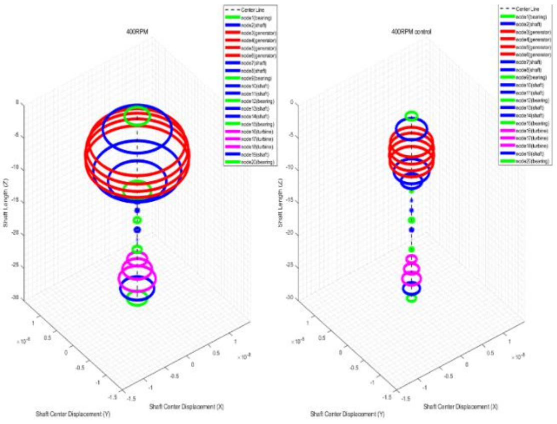

Figure 3. Comparison of system response before and after control at 600 rpm.

The control result at Node 12, which corresponds to the displacement measurement point in the actual experimental setup, is shown below.

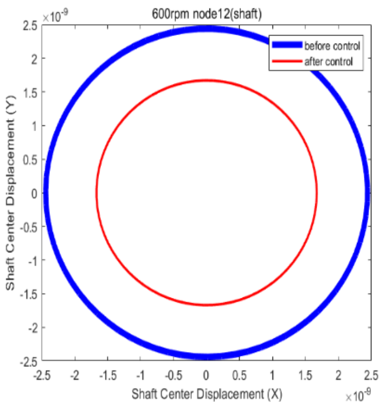

Figure 4. Shaft orbit at 600 rpm before and after control.

In the simulation, it was confirmed that the use of active bearing control effectively reduced vibrations, with a 31.54% reduction in amplitude observed after control.

4. EXPERIMENTAL RESULTS

4.1 Experimental setup

Figure 5 shows the experimental setup for evaluating the active bearing system. It consists of an unbalanced disk and two actuator-sensor modules mounted on a vertical shaft. The actuators apply control forces in the X and Y directions, while the sensors measure shaft displacement. All components are mounted on a rigid frame to reduce external disturbances.

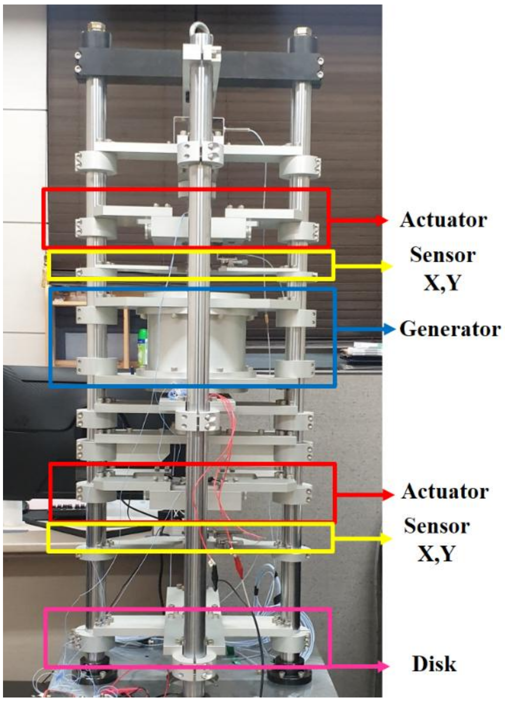

Figure 5. Experimental setup

Acceleration sensors in the X and Y directions send signals to Simulink via the d-SPACE platform. The NLMS algorithm processes the signals to generate control inputs, which are applied to piezoelectric actuators for real-time vibration suppression.

4.2 Experimental Results

Similar to the simulation results, the displacement response at 600 rpm was measured. The orbit plots before and after control are shown in the figure below.

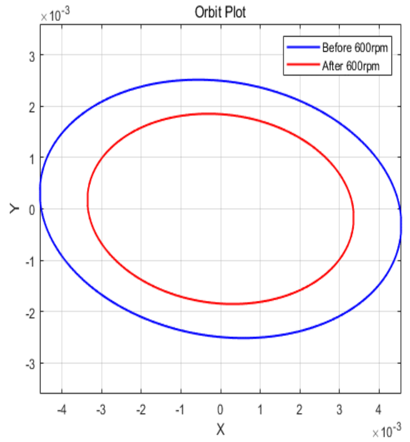

Figure 6. Shaft orbit at 600 rpm before and after control.

A 26.31% reduction in orbit amplitude was observed after applying the control.

5. CONCLUSION

In this study, an active vibration control method combining active bearings and the Normalized Least Mean Square (NLMS) algorithm was proposed to suppress transverse vibrations in vertically oriented rotating shaft systems. A vertical shaft model, including a generator and turbine, was developed using the Finite Element Method (FEM), and simulations were performed at 600 rpm using MATLAB and Simulink. The simulation results confirmed that the proposed method effectively reduced vibration amplitudes. To verify the practical effectiveness of the method, an experimental setup was constructed, featuring piezoelectric actuators and acceleration sensors. A real-time control loop was implemented using the d-SPACE system and Simulink, incorporating the NLMS algorithm. The experimental results showed a similar trend to the simulation, demonstrating significant vibration reduction at 600 rpm. These findings validate the potential of active bearings as a robust solution for vibration control in vertical rotor systems. The proposed approach can enhance operational stability and extend the service life of equipment such as hydroelectric generators and vertical electric motors.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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