Journal of Electronic Research and Application, 2025, Volume 9, Issue 4
http://ojs.bbwpublisher.com/index.php/JERA
ISSN Online: 2208-3510
ISSN Print: 2208-3502

Analysis and Research on Monitoring Devices for Deformation of Wind Turbine Pitch Bearing

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Abstract: The pitch bearing is a component in wind turbine units used to adjust the angle of the fan blades to adapt to the wind direction, so as to maximize the utilization of wind energy. Due to the different working mode of the pitch bearing itself compared with ordinary small bearings and the harsh working environment, the pitch bearing is prone to faults such as cracking and deformation. In severe cases, it will lead to overall damage to the pitch bearing, causing the blade to fall from a high altitude and even injuring personnel. Therefore, this paper conducts a patent analysis and technical decomposition of the deformation monitoring device for pitch bearings, analyzes and summarizes the development process of existing deformation monitoring devices for pitch bearings. Combined with the TRIZ evolution theory and based on the S-curve, it is concluded that the current deformation monitoring device for pitch bearings is in the transitional stage between the infant period and the growth period, and discusses the possible subsequent evolution directions. Through reviewing relevant literature, it is found that inner ring cracks first appear near the upper and lower surfaces of the bolt holes in the inner ring of the pitch bearing. To this end, a new type of deformation monitoring device for pitch bearings is designed. The fiber optic displacement sensor is used for qualitative monitoring of initial cracks near the surface of the bolt holes in the inner ring of the pitch bearing. After cracks are detected, the eddy current sensor is used for quantitative monitoring of whether there are extended cracks between the cracked bolt holes and adjacent bolt holes. Finally, the work done in this paper is summarized and prospected.

Keywords: Pitch bearing; TRIZ evolution analysis; Patent analysis; Innovative design

Online publication: August 7, 2025

1. Introduction

With the increasing proportion of clean energy [1], the reliability of wind turbine generator systems (WTGS), the core equipment for wind power generation, has become crucial. As a key component in WTGS for adjusting blade angles and transmitting loads, pitch bearings suffer from high failure rates due to harsh working conditions (low speed, alternating loads, limited rotation angle), which can easily lead to serious accidents such as blade loss of control and unit shutdown, as well as high maintenance costs [2–4].

To address this issue, foreign studies have focused on fault diagnosis methods (such as nonlinear filtering denoising and vibration analysis) [4–11], lubrication optimization, structural weak areas, and crack propagation laws, confirming that lubrication conditions, processing defects, and crack propagation are the main failure causes. Domestic research is dominated by patents, such as video monitoring by Goldwind Science & Technology, vibration detection by North China Electric Power University, and eddy current displacement monitoring [12–17]. However, these technologies are mostly in the initial stage, with issues such as insufficient monitoring depth and unvalidated diagnostic capabilities.

Patent analysis (combining quantitative and qualitative methods) reveals that the number of relevant patents in China is limited, with solutions mainly focusing on structural monitoring and lacking multi-sensor fusion and intelligent diagnosis. Based on TRIZ evolution theory, pitch bearing fault monitoring devices are currently in the transitional stage from the "infancy period" to the "growth period." Future technological breakthroughs should be achieved through multi-physical field monitoring, sensor integration, self-powered technology, and intelligent early warning systems to improve monitoring accuracy and reliability while reducing operation and maintenance costs.

2. Visual analysis of patent information on deformation monitoring devices for pitch bearings

Technical decomposition of the variable pitch bearing fault monitoring device, retrieval, and analysis of domestic patent information on the variable pitch bearing deformation monitoring device. Firstly, the monitoring device is technically decomposed into two categories: vibration signal detection and visual signal detection, covering components such as sensors, filtering modules, and wireless transmission. Vibration monitoring is achieved by obtaining operational status signals, but existing technologies have not been thoroughly processed and analyzed; Visual monitoring relies on image detection to detect macroscopic cracks, and both technologies have room for improvement.

According to patent searches, there were a total of 47 relevant patents in China from 2008 to 2021, with a peak of 18 patents in 2021, showing a steady growth trend in the past three years. The analysis of patent holders shows that enterprises lead research and development (45 cases, accounting for 88.24%), such as Beijing Goldwind Science and Technology Innovation and Wafangdian Bearing Group, while universities (such as North China Electric Power University) and research institutions contribute less (7.84% and 3.92% respectively), reflecting the vitality of enterprises in technology application, while university research focuses more on theoretical accumulation.

3. Technical characteristics analysis of variable pitch bearing deformation monitoring device based on TRIZ evolutionary path

Based on the TRIZ evolutionary theory, analyze the technological evolution path of the variable pitch bearing deformation monitoring device. According to the S-curve theory, the device is currently in the transitional stage from infancy to growth, with a small number of patents and insufficient product maturity, indicating significant room for research and development improvement. By applying the TRIZ Eight Evolutionary Laws to analyze the technical characteristics, it is found that:

The completeness rule requires monitoring devices to have four major modules: power, transmission, execution, and control. In the existing scheme, the execution device achieves data acquisition through a combination of vibration sensors and optical lenses, the transmission device adopts a guide rail slider structure for all-round monitoring, and the control device achieves data analysis and operation control through data processing modules and microprocessors, laying the structural foundation for subsequent innovative designs.

The rule of subsystem imbalance states that the execution device is the key bottleneck that restricts the development of the system. The current optical lenses can only detect surface cracks and cannot effectively identify near-surface or internal defects. New technologies such as eddy current sensors need to be introduced to enhance monitoring depth.

In terms of flexible evolution, it is pointed out that the transmission device can gradually upgrade from a rigid structure (fixed monitoring) to a multi-hinge telescopic rotating mechanism, and ultimately develop towards magnetic levitation non-contact monitoring to reduce mechanical wear and adapt to complex working conditions.

At the level of controllability evolution, it is pointed out that the monitoring system needs to be upgraded from manual indirect control to intelligent feedback control, automatically analyzing data through algorithms and triggering warnings to improve the timeliness and accuracy of fault response.

The hyper system transition rule emphasizes the integration of monitoring devices into the overall system of wind turbines (such as pitch bearings, wheel hubs, etc.), and achieves collaborative monitoring with the hyper system through non-contact technologies such as Hall sensors and eddy current sensors, optimizing resource integration and monitoring efficiency.

4. Innovative design of a variable pitch bearing deformation monitoring device

Analyze the future evolution direction of monitoring devices through the TRIZ evolution law. By analyzing the location of the crack in the pitch bearing, it was determined that the initial crack occurred on the surface near the bearing bolt hole. Therefore, the monitoring device needs to monitor the crack on the surface near the threaded hole (mainly the inner ring of the bearing). After determining the presence of cracks near the threaded hole, further monitoring of the extended cracks is required. Based on the future evolution direction of the monitoring device, the location of initial crack generation, and the development of extended cracks, it is believed that the actuator of the designed variable pitch bearing deformation monitoring device needs to include two types of sensors, namely the fiber optic displacement sensor that monitors the surface near the threaded hole and the eddy current sensor that monitors the propagation crack.

The overall variable pitch bearing deformation monitoring device is equipped with a horizontal bar fixed inside the blade. There is a motor at the center of the horizontal bar, and the motor shaft is matched with a fixed rod. The fixed rod can rotate around the inner ring of the variable pitch bearing, and an eddy current sensor is placed at its end. Near the threaded hole, there are fiber optic displacement sensors distributed at a 90° angle (**Figure 1**).

As the pitch bearing rotates, the fiber optic displacement sensor will monitor whether there are small cracks near the bolt holes of the pitch bearing. When it is determined that there are small cracks, the motor drives the connecting rod to rotate around the inner ring of the pitch bearing. The purpose is to move the end eddy current sensor to the vicinity of the small cracks on the pitch bearing, that is, between the bolt holes where the cracks appear and the adjacent bolt holes, to monitor whether the cracks are propagating. Fiber optic displacement sensors are used for qualitative monitoring, while eddy current sensors are used for quantitative monitoring.

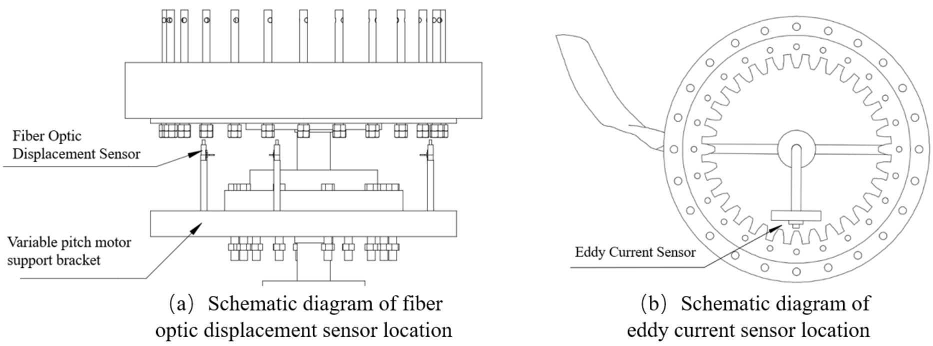

Figure 1. Schematic diagram of the placement of fiber optic displacement sensor and eddy current sensor

The overall monitoring device is shown in **Figure 2**. Due to the fixed support frame of the pitch motor on the wind turbine, the pitch motor is maintained in a fixed state relative to the ground through the fixing of the pitch motor support frame. The gear structure at the top of the motor drives the inner ring of the pitch gear to rotate.

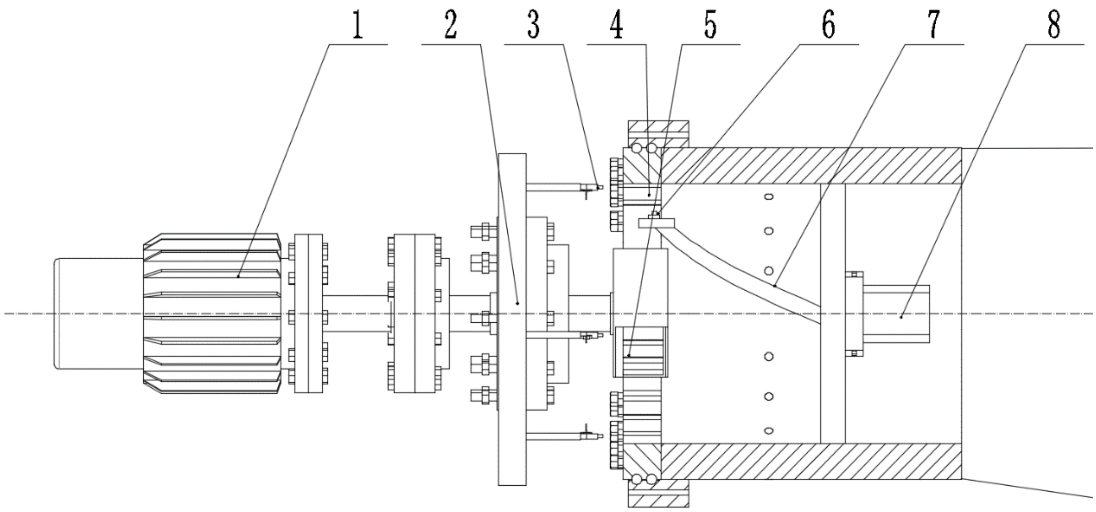

Figure 2. Schematic diagram of variable pitch bearing fault monitoring device: 1- Pitch motor 2- Pitch motor support frame, 3- Fiber optic displacement sensor, 4- Pitch bearing, 5- Pitch motor gear, 6- Eddy current sensor, 7- Fixed frame, 8- Fixed frame motor

When the inner ring of the pitch bearing rotates at a certain speed, the fiber optic displacement sensor on the pitch motor support frame will monitor the surface cracks near the bolt holes of the pitch bearing at regular intervals based on the rotation speed, and the interval time can be manually adjusted.

When the fiber optic displacement sensor detects abnormal displacement, it will send a signal to the microcontroller, which drives the fixed frame motor to rotate to the vicinity of the abnormal position monitored by the fiber optic displacement sensor, start the eddy current sensor, and perform crack monitoring.

Disclosure statement

The author declares no conflict of interest.

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