Real-Time Monitoring Of Transmission Shaft Using Low-Cost Sensors Systems

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Abstract

Thispaper gives the idea about real-time monitoring of transmission shaftsby using cheaper and more accurate ways to monitor the health of a shaft during the operational condition and predict possible failure. Sensor technology is used as a data collection system. Deflection and speed are important parameters for stress in a mechanical system. Data will be collected to do the prediction of shaft health in real-time. The reliability and performance of mechanical systems are often contingent on the health of their transmission shafts. Real-time monitoring of these components is crucial for early detection of faults, reducing downtime, and ensuring operational safety. This research paper presents a comprehensive study on the development and implementation of a low-cost sensor system for real-time monitoring of transmission shafts. The study explores sensor selection, system design, data acquisition, signal processing, and fault detection techniques, aiming to provide an economical yet effective solution for industries relying on heavy machinery.

Keywords: - Shaft, failure, real-time, health monitoring, sensors, prediction.
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I. INTRODUCTION

In this paper,we illustrate the method to monitor the transmission shaft deflection, vibration, stress, torque, etc. all this parameters value obtains using data collection software and controller. Based on data analysis results prediction of shaft failure could be performed.Sensors are going to collect data with help of the controller which is set by the programming taking the data after an equal interval of time and variation of speed in the shaft. A computer with appropriate data analysis software will be placed to display the received data in real-time. Statistical tools are going to be used for the optimum result.

Vibration can be described using amplitude, velocity, and acceleration. There are many types of sensorsthat have been used to record vibration like a surface acoustic wave 0 and optical sensor 0 but these sensor systems are costly, thus a system based on a piezo vibration sensor with a controller is proposed.

Transmission shafts are critical components in various industrial and automotive applications, transferring power from the engine to the wheels or other machinery. Their health and performance are vital for the smooth operation and safety of the entire system. Traditionally, monitoring the condition of these shafts has been a challenging and often expensive task, involving high-end sensors and complex analysis techniques. However, with advancements in sensor technology and data processing, there is a growing opportunity to implement real-time monitoring using low-cost sensor systems. This can significantly enhance predictive maintenance, reduce unplanned downtime, and improve overall system reliability.

1.2. Challenges in Transmission Shaft Monitoring

The challenges in monitoring transmission shafts stem from the harsh operating conditions,

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and exposure to extreme temperatures and vibrations. Accurately detecting anomalies or signs of wear under these conditions requires sensitive and reliable sensors. Additionally, the integration of these sensors into existing systems without causing disruptions or requiring extensive modifications is another critical challenge.

1.3. Objectives of the Study

This study aims to design and validate a low-cost sensor system for real-time monitoring of transmission shafts. The specific objectives are:

a) To identify suitable low-cost sensors capable of withstanding harsh operational environments.
b) To develop a system architecture that allows for effective data acquisition, transmission, and processing.
c) To implement signal processing and machine learning algorithms for accurate fault detection and predictive maintenance.
d) To evaluate the performance of the developed system through rigorous testing and compare it with existing high-cost solutions.

II. Literature Review

Structural Health Monitoring (SHM) has gained a lot of attention in the last few decades as an effective tool for the assessment of the structural integrity of civil infrastructure. However, the reliability of SHM systems is a crucial concern, as it affects the accuracy and effectiveness of the system in detecting any potential defects or damages. The current literature on SHM reliability focuses on different aspects of SHM systems, including sensor selection and placement, data acquisition and processing, noise reduction, and calibration and maintenance.

Several studies have investigated the reliability of different types of sensors used in SHM. Zhou et al. (2021), they evaluated the reliability of four different types of strain sensors, including fibre Bragg grating (FBG), electrical resistance strain gauge (ERSG), piezoelectric ceramic (PZT), and optical fibre Fabry–Perot (OF-FP) sensors. They found that FBG sensors provided the most reliable and accurate data, while PZT sensors had the highest measurement error.

In terms of data acquisition and processing, advanced signal processing techniques have been proposed to improve the reliability of SHM systems. For instance, Liu et al. (2020) used a deep learning-based method for damage detection in concrete beams using acoustic emission signals. The study showed that the proposed method could achieve higher accuracy and reliability than traditional signal processing techniques.

Noise reduction is another critical factor in the reliability of SHM systems. Koo et al. (2021) proposed a wavelet-based denoising method for SHM data, which effectively removed noise and improved the reliability of the system. They compared the method with conventional denoising techniques and found that the proposed method outperformed them in terms of signal-to-noise ratio.

Regular calibration and maintenance of SHM systems are also crucial for ensuring long-term reliability. In a study by Zhao et al. (2019), they investigated the impact of temperature on the reliability of fibre optic sensors used for SHM. The study showed that temperature changes could lead to significant errors in the sensor readings and recommended regular calibration of the sensors to maintain reliability.

In conclusion, the current literature suggests that SHM systems can be highly reliable when appropriate sensors are selected and placed, advanced signal processing techniques are used, noise is effectively filtered, and the system is well-maintained and calibrated. However, more research is needed to investigate the long-term reliability of SHM systems and their effectiveness in real-world scenarios.

III. Methodology

This methodology provides a structured approach to developing a low-cost sensor system for real-time monitoring of transmission shafts. The subsequent sections will discuss the detailed system design and implementation, data processing techniques, and experimental results.

There are multiple types of sensors used to monitor shaft health. But these are very costly. The idea is to minimize the cost by using the low-cost controller and transducers.

Vibration measurement system can be explained with this block diagram in fig.1.

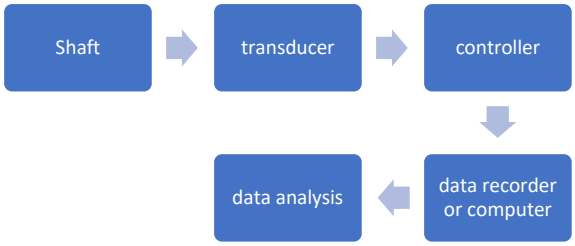

Fig.1 Principle of Vibration measurement

Structural health monitoring has been used last 2 decades in the field of civil engineering and aerospace industry but its use in mechanical engineering is very limited. This gives us freedom to select the SHM method in transmission shaft. Most of the structural health monitoring done by analysing the data acquired by the sensors or transducer at particular time period so there is gap between the actual condition of the structure and data acquired.

As per ISO2372 standard for vibration severity machine having power below 20 HP comes under class-I, power 20-100 HP comes under class-II, and power above 100 HP comes under class-III. We have peak and RMS value of vibration severity range as per the value of peak and RMS A, B, C, and D grade were defined A-Good, B-Allowable, C- tolerable and D- not permissible.

3.1. Sensor Selection Criteria

The selection of sensors is crucial for the success of the monitoring system. The criteria for selection include:

Cost-Effectiveness: Sensors should be affordable to align with the goal of developing a low-cost system.
Durability and Reliability: Sensors must withstand harsh operational environments, including high vibration levels, temperature fluctuations, and potential exposure to contaminants.

Sensitivity and Accuracy: The ability to detect minute changes or anomalies in the shaft's operation is essential.

Ease of Installation: Sensors should be easy to install and require minimal modification to the existing machinery.
Based on these criteria, a combination of accelerometers, temperature sensors, and strain gauges were selected for the initial prototype.

3.2. System Architecture

The system architecture consists of the following components:

Sensors: To capture relevant data from the transmission shaft.

Data Acquisition System (DAQ): To collect and initially process the sensor data.

Wireless Communication Module: To transmit data to a central processing unit or cloud storage.

Central Processing Unit: For advanced data processing and analysis.
User Interface: To display real-time data and alerts to the operators.

3.3. Data Acquisition and Transmission

The DAQ system is designed to be robust and capable of handling high-frequency data from the sensors. The data transmission is achieved using a wireless communication module, considering factors such as range, bandwidth, and power consumption. The choice of communication technology (e.g., Wi-Fi, Bluetooth, LoRa) is based on the specific industrial environment and the distance between the machinery and the central processing unit.

3.4. Power Management for the Sensor System

Power management is a critical aspect, especially for wireless sensor nodes. The system is designed to be energy-efficient, with options for battery operation and energy harvesting solutions where feasible. Power-saving modes and intelligent data transmission strategies are incorporated to extend the lifespan of the sensors and reduce maintenance.

IV. THEORY

Shaft frequency can be calculated by using equation

$$-\rho\omega^2\mathbf{u} = \nabla\cdot(\mathsf{F}\mathsf{S})^{\mathsf{T}},\quad \mathsf{F} = \mathsf{I} + \nabla\mathbf{u},\quad -i\omega = \lambda$$

Where,
ρ = Density of materials.
ω = Angular velocity
u = Linear Velocity

V. Experimental Setup

After CAD modeling simulation study result were satisfactory to make the experimental setup. Miniature shaft of length 18 inch and 3.89 mm diameter of ASI Steel 4340 is selected. Shaft is connected with high-speed DC motor and other end is connected with bearing support. This shaft component is mounted on wooden frame of 6 inch wide and 24inch in length. Wooden frame is used so that we can easily mount the sensors and controller on it.

Fig.2 CAD model of Experimental Setup

VI. System Design and Implementation

The design and implementation of the low-cost sensor system for real-time monitoring of transmission shafts are detailed in this section. It encompasses hardware components, software framework, sensor integration, and calibration procedures.

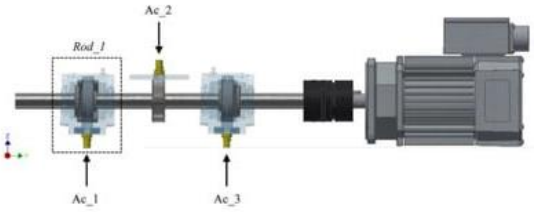

Fig.3 Sensor Position

4.1. Hardware Components

The hardware components of the system include:
Sensors: Accelerometers, temperature sensors, and strain gauges were selected based on the criteria outlined in the methodology. These sensors are capable of capturing vibration, temperature, and stress data from the transmission shafts.

Data Acquisition System (DAQ):A microcontroller-based DAQ was developed. It interfaces with the sensors to collect data and preprocess it for transmission. The DAQ is designed for low power consumption and high data throughput.

Wireless Communication Module:A Wi-Fi module was chosen for its balance between range and power consumption. It facilitates real-time data transmission to the central processing unit.

Power Supply: A combination of battery power and energy harvesting (using piezoelectric materials) was implemented to ensure continuous operation.

4.2. Software Framework

The software framework includes:

Firmware for Microcontroller: Responsible for sensor data collection, initial processing, and managing wireless communication.

Data Processing and Analysis Software: This software, running on the central processing unit, applies advanced signal processing and machine learning algorithms for fault detection and predictive maintenance.

User Interface (UI):A web-based UI was developed for easy monitoring. It displays real-time data, trends, and alerts.

4.3. Integration of Sensors

The sensors were integrated onto the transmission shafts with attention to minimizing their impact on shaft operation. Custom mounts were designed for the accelerometers and strain gauges to ensure secure attachment and optimal data collection. The temperature sensors were placed in strategic locations to monitor the thermal profile of the shaft.

4.4. Calibration and Validation Procedures

The system underwent rigorous calibration and validation:

Sensor Calibration: Each sensor was calibrated against known standards to ensure

accuracy.

System Validation: The entire system was tested on a benchtop setup simulating operational conditions of transmission shafts. Parameters such as sensor placement, data acquisition rates, and wireless transmission were optimized.

Field Trials: Preliminary field trials were conducted in an industrial setting to validate the system's performance under real operational conditions.

The design and implementation of this low-cost sensor system demonstrate its potential for effective real-time monitoring of transmission shafts. The next section will discuss data processing and fault detection techniques utilized in the system.

VII. Result and Discussion

The results demonstrated the system's capability to detect and differentiate between normal and faulty conditions effectively. Key findings include:

Fault Detection: The system successfully identified instances of misalignment and imbalance. The vibration data from accelero-meters were particularly useful in these detections.

Temperature Monitoring: Temperature sensors provided valuable insights into overheating issues, which could be indicative of excessive friction or lubrication problems.

Strain Measurements: Strain gauges captured data that helped in understanding the stress distribution along the shaft under different load conditions.

One notable observation was the system's sensitivity to environmental noise. Additional signal processing techniques were imple-mented to filter out irrelevant noise for more accurate fault detection.

6.4. Comparative Analysis with High-Cost Systems

A comparative analysis with high-cost monitoring systems showed that while the developed system had slightly lower sensitivity and data resolution, it was still effective in fault detection and monitoring. The cost-benefit analysis indicated that the low-cost system provided a significant economic advantage, making it a viable option for small to medium-sized enterprises.

The results underscore the potential of low-cost sensor systems in industrial monitoring applications. Despite certain limitations in sensitivity and resolution, the system offers a cost-effective solution for real-time monitoring of transmission shafts, with the capability to significantly improve maintenance strategies and reduce downtime.

The subsequent sections will delve into the challenges and limitations encountered during the study, followed by potential applications and future research directions.

VIII. Conclusions

This paper is written about how to minimize the cost of SHM in slender structures like shafts by using an alternative sensor technology system so that this setup can be implemented for the real-time health monitoring of shafts.

This study successfully demonstrated the feasibility and effectiveness of using low-cost sensor systems for real-time monitoring of transmission shafts. The developed system, comprising accelerometers, temperature sensors, and strain gauges, coupled with a robust data acquisition and processing frame-work, proved to be a viable alternative to traditional, high-cost monitoring solutions.

Key conclusions drawn from the study include:
Effective Fault Detection: Despite its low-cost nature, the system effectively detected common faults in transmission shafts, such as misalignment, imbalance, and overheating.

Cost-Efficiency: The system provides a cost-effective solution for continuous monitoring, making it accessible to a wider range of industrial applications, particularly for small and medium-sized enterprises.

Real-Time Monitoring and Predictive Maintenance: The ability to monitor transmission shafts in real time and predict

potential failures can significantly enhance maintenance strategies, reduce unplanned downtime, and improve overall system reliability.

Challenges and Limitations: While the system showed promising results, challenges such as sensitivity to environmental noise and slightly lower data resolution compared to high-end systems were observed. Future iterations of the system could focus on addressing these limitations.

Broader Applicability: The principles and technologies employed in this system have broader applicability and can be adapted for monitoring various other types of industrial machinery and components.

In conclusion, this study contributes to the growing body of knowledge in the field of industrial monitoring and predictive maintenance. It demonstrates that with careful selection of sensors, intelligent system design, and advanced data processing techniques, low-cost sensor systems can play a significant role in enhancing the monitoring and maintenance of critical industrial components like transmission shafts. This approach holds great promise for improving operational efficiency, safety, and sustainability in various industrial sectors.

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