https://doi.org/10.46335/IJIES.2024.9.8.8 e-ISSN: 2456-3463
Vol. 9, No. 8, 2024, PP. 34-42

International Journal of Innovations in Engineering and Science, www.ijies.net

Machine Fault Detection Using Condition Monitoring Techniques: A Review

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Received on: *05May, 2024* ***Revised on***: *03 July, 2024* ***Published on***: *06 July, 2024*

Abstract -

This research proposes an integrated approach that combines many condition monitoring approaches for equipment failure identification. It looks at acoustic emission, vibration analysis, thermography, oil analysis, and each of these analyses offers a different perspective on the condition of the equipment. The objective is to maximize the combined potential of these methods to raise the precision and consistency of defect uncovering. Toward increase the accuracy and consistency of fault identification, the research highlights the need of integrating different monitoring systems. In addition, it highlights areas that need further research and talks about future directions for machine fault detection. To help researchers, practitioners, and business professionals maximize the potential of condition monitoring to improve equipment performance and reliability, the article provides useful information about the numerous condition monitoring techniques used to discover machine failures. It highlights recent advancements and provides a summary of existing information.

Keyword- *Analysis, condition monitoring technique, DAQ System, machine, vibration.*

Introduction

Condition monitoring, or CM, is the procedure of continuously monitoring an equipment's state, such as temperature, vibration, etc., to identify any changes that would indicate the start of a problem. Because condition monitoring makes it possible to schedule maintenance and take preventative action to avoid subsequent failure and the ensuing unanticipated shutdown, it plays a vigorous part in predictive maintenance. Condition monitoring processes are practical to a extensive assortment of equipment, such as auxiliary systems, motors, pumps, and rotating machinery. Condition monitoring describes advanced,

State of-the-art techniques that use sensors to evaluate many parameters in real time and can trigger an alarm upon detecting a change. Vibration analysis served as the foundation for most of traditional condition monitoring.

Importance of condition monitoring

Condition-based monitoring, which is used in maintenance, looks at asset health to identify what needs to be fixed and when. The goal is to reduce wasteful procedures, downtime, and asset failures. For every predictive maintenance plan, it might be deemed indispensable. Only when specific thresholds are crossed or indicators point to impending failure or declining performance, is maintenance necessary, according to condition-based monitoring.

In the past, non-invasive measures, visual inspections, performance statistics, planned testing, and completion at pre-set or predetermined intervals were used to monitor a machine for certain thresholds and signs. On the other hand, condition-based monitoring scans for probable failure modes by first examining their signs.

Temperature tracking, vibration analysis, and vibration monitoring are examples of common condition-based growth. To enhance, monitor, and preserve the performance of their gear, manufacturers have searched for condition monitoring systems.

Machine condition monitoring is very sought after because of its capacity to examine the characteristics of the equipment and look for any changes that could indicate an imminent failure or prevent a breakdown. This approach is being used more often in several industries, such as metal and mining, oil and gas, power generation, automotive, marine, and aerospace.

Condition monitoring Techniques

1. Acoustic Emission

The rapid release of energy from certain sources, exclusive of a material, that results in transitory elastic waves is known as acoustic emission (AE) [1]. By spotting early warning indicators of impending damage or failure, AE can enable preventative maintenance or repair. In tests of static strength verification for carbon fibre composite wings and vertical structures, AE has been used to identify and locate errors [1]. Because it is a non-destructive testing

monitoring techniques. Sensors collect data in real-time, giving continuous asset health the aim of condition-based maintenance is to anticipate equipment failure so that preventive maintenance can be planned for when it is needed, rather than before. Predictive maintenance and preventative maintenance differ in part because of this Monitoring and testing.

The condition monitoring scheme market is projected to reach a assessment of US$ 3,776.1 million by 2023. According to Upcoming Market Insights, the market will expand at a compound annual growth rate (CAGR) of 7.7% and reach a assessment of US$ 7,928.7 million by 2023.

The need for advanced diagnostics to evaluate the machine's condition and facilitate industry

procedure, it may be used without endangering the material being examined [1].

High-quality equipment or devices are used in Acoustic Emission (AE) testing types to identify the problem.AE makes use of a wide range of instruments and sensors, such as laser vibrometers, transducers, preamplifiers, and capacitance sensors. Piezoelectric material with a brand width of 0.1 to 2 is used to make sensors in AE [2] [3]. Because of its great sensitivity, lead zirconate titanate (PZT) is the material that is most utilized for piezoelectric devices [2].

In AE, unwanted noise is removed from a signal by casting off the denoising procedure, which allows for a more accurate depiction of the underlying data. It is essential for raising analytical accuracy and the signal-to-noise ratio (SNR) [2]. Time-domain analysis and wavelet transform are the most popular methods for analyzing acoustic emissions; they are still used to identify, examine, and comprehend elastic waves that are caused by internal material variations [2] [4]. The partial discharge method,

https://doi.org/10.46335/IJIES.2024.9.8.8 e-ISSN: 2456-3463
Vol. 9, No. 8, 2024, PP. 34-42

Fast Fourier transform (FFT) analysis, and structural health monitoring methods are shown to be overly tolerant in determining machine malfunctions [1] [3]. The AE signal was examined using the EI (Energy Index) perception, with encouraging outcomes [4]. Acoustic emission is a vital equipment to evaluate the structural well-being and durability of materials, and it is frequently utilized in industries where tracking to prevent future failures is required.

2. Shock pulse analysis

The Shock Pulse Method (SPM) is a condition monitoring method used for sensing and measuring the status of rolling component bearings, which are originate in rotating equipment including motors, pumps, and further manufacturing equipment. Single pulse and spectral analysis are captious for sympathetic the assets of shock pulses formed by rotating apparatus [8]. The shock pulse technique uses an accelerometer and a velocity sensor to identify bearing vibration While analysis software tools evaluate and examine the data for additional diagnosis, data acquisition systems seize and digitize signals from a variety of sensors
[5].

The shock pulse technique, or dBm/dBc, is used to assess rolling bearing working problems by producing electric pulses proportionate to shock magnitude. The transducer converts shock pulses into electric signals, which are analysed to provide peak and carpet values. The LR/HR method provides calculation models for optimal lubricant selection by analysing oil film state in rolling element bearings. The method requires precise information on bearing size, speed, geometry, and oil film condition. Time-frequency analysis techniques are widely utilized to assess rolling bearing health and extract passing fault topographies [5]. By analyzing frequency-domain shock pulse readings, the 'SPM Spectrum' may identify the source of the shocks and reveal patterns resulting from gear and bearing deterioration as well as random shocks from disturbance sources. A direct shock value that simulates the bearing problem may be proposed by SPM [6]. Reports on SPM Analysis By monitoring the thickness of the lubricating oil and the condition of the rotating bearings, maintenance personnel may perform efficient preventive maintenance [6]. Comparable to
vibration-based detection, this approach of identifying bearing problems is also straightforward, efficient, and easy to use. The SPM rely on the resonance response at the inherent frequency of the sensor being triggered by a bearing malfunction shock [5]. A legal assessment of the operating disorder of rolling element bearings may be made using the three condition zones that the SPM theory distinguishes between: healthy, weak, and severe damage zones [5]. The vibration gadget uses real-time data gathered through several signal processing techniques to locate and identify bearing faults [6]. Shock Pulse Analysis is a predictive maintenance tool that detects early issues, reduces costs, and prevents unplanned downtime. The type of equipment, the industrial process, and the quality of the data all affect its effectiveness. For a thorough examination of the health of machinery, it is frequently used in conjunction with other methods.

3. Temperature Analysis

Thermal analysis encompasses a range of methods whereby a sample's attribute is consistently monitored while the sample is subjected to a preset temperature profile.

The novel approach to condition monitoring for wind turbine generators is put forth, which is predicated on the nonlinear state approximation method. The method is applied to build the electrical system's typical behaviour model. When there is a discernible difference between the measured generator temperature and the model estimates, it is an indication of impending generator failure.

The Supervisory Control and Data Acquisition (SCADA) system regularly measures temperatures, which are significant and effortlessly quantifiable indications of the condition of various wind turbine components. Unexpectedly high component temperatures could be a sign of overburden, inadequate
lubrication, or perhaps unsuccessful inert or lively cooling. A generator gearbox normal temperature model is built by using SCADA data by applying Neural Network. The authors described in a method for utilizing multiple layer perception (MLP) to create a temperature archetypal of the gearbox. Each report includes the following information: time stamp, output power, stator current and voltage, wind speed, ambient and nacelle temperatures, and generator stator winding. This research proposes a nonlinear state estimate technique (NSET) based temperature trend scrutiny approach [8].

An essential component of mechanical system reliability management is gear unit condition monitoring. Analyzing trash, sound, or vibration are tried-and-true methods for carrying out condition monitoring. An alternate to traditional approaches for identifying gearbox breakdown is to use temperature as a condition indicator. There is a difference between a contact temperature sensor (like a thermocouple) and a noncontact temperature sensor (like a thermography) depending on the type of failure and the measurement technique. Shafts, gears, and bearings are the three primary parts of a typical gear unit. Both gears and bearings experience power losses during operation because of the interactions that occur at the point where two moving elements come into contact. The load-dependent losses and the no-loaddependent losses can be distinguished as the two primary sources of these losses. Losses that depend on no load are related to the relative motion of a solid surface and a fluid. Data from a thermography (temperature matrix) differ as of those as of a contact sensor (single point measurement), suggesting that the temperature measuring method affects diagnostic capabilities and methodology.

In addition, this temperature method might work well for pad bearing health monitoring. Certain common studies, such vibrational monitoring and electrostatic monitoring, are not achievable with these bearings since they employ fluid as both a surface separator and polymer pads. This is because the oil film dampening effect makes vibrational monitoring challenging. The literature evaluation indicates that temperature health monitoring presents a viable substitute for acoustic or vibrational health monitoring.

Certain factors can be evaluated without direct measurement by measuring the temperature of the oil [9].

Turbo-generator setups require a lot of data. Even a seasoned analyst may find it difficult to diagnose problems with these systems because numerous sensors are needed at each bearing point. Therefore, the goal of this research is to create a defect diagnosis technique that is as simple as possible and only requires one vibration and one temperature sensor per bearing. The aim of this project is to provide a diagnosis method that maintains a low computational load while utilizing fewer sensors. The goal is to maintain simplicity in both data collection and processing. There is a chance to combine temperature and vibration data for efficient FD because temperature monitoring systems are widely available on revolving machinery in industries and studies have shown that temperature measurement is sensitive to rotating machinery problems. Temperature and vibration data are gathered and compared to a healthy state to check for coupling misalignment, rotor rub problems, and fractured rotors. Vibration spectrum analysis is done the traditional way. first as a point of reference. After that, two diagnostic techniques are conducted by combining the results of the whole vibration analysis with temperature data. Good results were obtained without the cost of complicated signal processing, such as phase and order tracking, by combining temperature with vibration data. [10]

4. Wear Debris analysis

Wear Debris: Wear phenomena typically affect parts like gears, bearings, pumps, hydraulics, and motors while they are in use. Tiny debris particles, ranging in size from 1 to 10 microns, are produced during regular machine operation. When abnormal wear begins, large debris particles between 10 and 150 microns in size are created. Particle concentration and size will steadily rise until the machine breaks down. To Prevent machine failure continuous monitoring is required. To identify the wearer particles that are found in the lubricating oil, a device has been developed and evaluated in this work. Regular collections of oil samples are used to test for the presence of worn-out particles. A photo diode can detect worn-out particles, both ferrous and nonferrous, and then blink an LED and a buzzer circuit to sound. The oil tube is surrounded by a magnet that the device uses to detect ferrous particles. The benefits of the suggested methods are simple, devoid of complex sensors and their workings, easy to use [11].

In this paper a technique is used to analyzing wear debris from gear debris are using computer image analysis. The six-parameter used to describe wear debris particles are reflectivity, elongation, fibre ratio, simplified contrast value, average diameter, and roundness. The morphological and optical characteristics of wear debris particles gathered on filters are described by these six factors. The method is applied to monitor gear wear in a pitting test under constant load and standard gear oil tests where load was increased. In the pitting test, increased in average particle diameter and roundness indicated progression of fatigue wear leading to pitting failure. In the increasing load tests, dark rough particles generated at higher loads could signal impending scuffing damage at even higher loads. Particles types were classified and their distribution over test stages provided information about gear wear conditions.[12]

The study on mechanical wear debris is included in this work, along with the use of debris data fault diagnosis, analysis of wear processes debris feature, and detection

https://doi.org/10.46335/IJIES.2024.9.8.8 e-ISSN: 2456-3463
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techniques. Three primary wear processes are described: 1) Friction wear, 2) abrasive wear, and 3) adhesive Wear Debris characteristics that reveal the kind and degree of wear include size, morphology, and composition. Detection method include offline principle. Online monitoring allows debris generation profiles to be examined for diagnosing machine condition and predicting remaining useful life. Challenges remain in distinguishing debris sources and Quantifying wear process [13]

5. Thermography

This paper describes an experimental study that evaluated the condition of a turning operation using infrared thermography technology. The vibration and temperature changes that happen when 316l steel is rotated are monitored by the research using an infrared thermography camera and a laser ,Vibrometer Doppler. Analysis is done on the impact of machining parameters on vibration, temperature, and tool wear, such as feed rate, depth of cut, and cutting speed. During testing, carbide inserts with and without coatings are employed. Thermography data indicate that as feed rate and cutting speed rise, so does tool temperature. As the cutting speed increases, so do the vibrations. Compared to uncoated inserts, coated inserts produce less heat and exhibit a consistent temperature and vibration trend with tool wear. The study demonstrates the viability of utilising thermal and vibrations data for online monitoring of high-speed turning operations [14]

The application of active and passive thermography methods for wind turbine blade condition monitoring is examined in this research. Because passive thermography doesn't require specialized equipment or active lighting like lamps, it's highly useful for examinations in dim or confined spaces. Active thermography is the process of lighting objects with infrared light using emitters, then using an infrared camera to take photos. For the investigation, two different kinds of blades are employed. The damaged blade part was first, followed by a test plate with holes bored into it artificially. To find subsurface flaws in the plate, thermography with pulsed and step heating was applied. Defects identification was enhanced by image processing techniques such as phase/amplitude analysis and matching filters. The blade section's passive thermography was discovered. The blade section's passive thermography revealed that midday was the optimal time for cracks and delamination while early morning offered higher contrast. Transform-based techniques improved passive results. Active thermography detected smaller defects but images processing was needed for both active and passive results.[15]

6. Ultrasonic wave

One kind of non-destructive testing is ultrasonic analysis. We are able to identify severe faults in the materials by analyzing the way sound waves propagate through them.

The ultrasonic pulse wave velocity trial is assessed as a probable technique of monitoring mixture integrity vicissitudes caused by moisture. There were two sets of mixtures created. The Florida Department of Transportation (FDOT) often utilizes limestone mixes with coarse-grained material (below the

circumscribed zone) and fine-grained material (above the limited zone) in the first category.

The ultrasonic pulse wave velocity trial was used to examine the vicissitudes that followed in the mixes. Before

https://doi.org/10.46335/IJIES.2024.9.8.8 e-ISSN: 2456-3463
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and after conditioning, an ultrasonic pulse wave velocity trial was executed to provide a temporal history of the effects of wetness in the mixtures. Furthermore, a pulse wave velocity trial was castoff to determine how aggregate structure altered the impacts of porewater in a mixture. A modest strain modulus that seems toward follow predictable patterns in air voids and density was acquire from the ultrasonic pulse wave velocity test. The ultrasonic pulse wave velocity test seems designate impacted by moisture conditioning and porewater effects. The test seems to be susceptible to vicissitudes in mixture integrity caused by humidity conditioning [16].

Information on the oil-continuous oil-air-sand and oil-air-water combinations ultrasonic attenuation and transit time via steel pipes. The most common type of production separator is the gravity separator, which comes in a range of sizes and forms. Test separators are too castoff to distinct the well flow for scrutiny and accurate flow monitoring. The goal of multiphase flow metering (MFM) is to determine the various component flow rates of a multiphase stream, such as gas, water, and oil. The topic of whether ultrasonic can be used as a water cut meter arose because of its extremely low sensitivity to the water cut. One possible direct replacement for the gamma-ray sensors and capacitance probes is the ultrasonic approach. As an alternative to the gamma-ray method, ultrasonic technology would seem to offer the advantages of being far less costly and not requiring radioactive sensors [17].

This study's primary emphasis is the use of acoustic and ultrasonic methods for the uncovering and valuation of leaks, obstructions, and flaws in subterranean pipelines. The active (pinging) and passive (listening) acoustic modes of operation comprise acoustic technology. Pinging is the process of creating pings, which are transmitted acoustic pulses that are transformed from electrical energy into sound energy by an active acoustic transducer. In subsurface water and wastewater/sewerage pipe networks, ultrasonics and passive and active acoustics are now the most widely employed sensors; however, additional technologies like CCTV, laser Magnetic flux leakage (MFL), Eddy Current Testing (ECT), and profiling are also utilized.

One transducer (pulse-echo) or two transducers (pitch-catch), which are normally affixed to the exterior of the pipe, make up a typical setup, as shown in Fig. 1(a)(b). Ultrasonic bulk waves are often produced by piezoelectric ceramics or polymers that need interaction with a fluid or compact couplant. This study examines the application of acoustic and ultrasonic technology for subsurface water systems and surplus water/sewerage tube networks condition monitoring. While these approaches have been practical manually to pipes or placed on human-controlled robots, they are very appropriate for use in tandem with independent checkup robots to identify the first signs of tube problems [18].

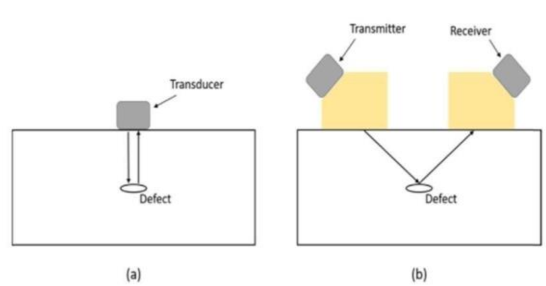

Fig 1 schematic diagram of (a) pulse-echo and (b) pitch-catch ultrasonic bulk wave setup[18]

https://doi.org/10.46335/IJIES.2024.9.8.8 e-ISSN: 2456-3463
Vol. 9, No. 8, 2024, PP. 34-42

International Journal of Innovations in Engineering and Science, www.ijies.net

7. Dynamic analysis of vibration analysis

Dynamic analysis is analyzing and testing a program while it is running. Dynamic analysis, sometimes referred to as continuous code scanning, improves the detection and correction of runtime errors, memory issues, and software failures.

In a wide range of industries and power plants, electrical machines are widely utilized and indispensable. Monitoring the status of electrical machineries is essential for identifying the manufacturing processes that are further well-organized and have less downtime.

Recurrent condition monitoring is becoming more and more necessary because to the rising occurrence of different machine failure types under changed operating situations. In all electromechanical schemes, vibration has long been recognized as one of the primary pointers of the mechanism's underlying corporal behaviour and additional external disturbances. Real-time vibration scrutiny has been carried out on a DC motor shaft under various effective situations in order to ascertain the vibration pattern that corresponds to the operating conditions and is connected to an AC generator. The statistical classification-based decomposition approach is built on the LabVIEW platform to extract the random vibration [19]. This study proposed the use of groundbased microwave interferometry and extreme-point symmetric mode decomposition (ESMD) for dynamic vibration characterization and monitoring of ancient bridges. Ground based microwave interferometry: a novel High accuracy non-contact innovation is castoff to acquire dynamic time series displacements with environmental excitation factors and a transient load with a car, respectively. The ESMD approach, a novel replacement for the Hilbert-Huang transform (HHT) method, is used to the immediate vibration analysis of Zhaozhou Bridge. First, an ideal adaptive global mean (AGM) curve and a sequence of intrinsic mode functions (IMFs) are generated using a mode symmetric about the maxima and minima sites. Second, the instantaneous frequency of each IMF is found using:

(1) decomposition to produce a set of IMFs and an appropriate adaptive global mean (AGM) curve; and (2) direct interpolation technique to provide the instantaneous frequency for each IMF. If the instantaneous frequency acquired by HHT curve has any tiny abrupt shifts, it might be challenging to determine the slight damage. On the other hand, the ESMD technique exhibits a constant obtained maximum instantaneous frequency [20].

8. Oil analysis of condition monitoring

An essential component of any predictive maintenance plan is OCM (Oil Condition monitoring). OCM involves pursuing the corrosion of oil excellence as of novel to end-of-life and measuring, monitoring, and analyzing vicissitudes in fuel and lubricant oils for adulteration and chemical composition.

The paper discusses the importance of spectrometric analysis in detecting abnormal wear in machines and engines, particularly focusing on the significance of monitoring particle size distribution. It implies that while rotating disc electrode (RDE) spectrometers are sensitive to bigger particles up to around 10 micro meters, approaches like atomic absorption spectroscopy (AAS) and inductively coupled plasma (ICP) spectrometers may have deficiencies in particle identification. To enhance the effectiveness of spectrometric analysis, it proposes a "differential method" involving two measurements on each sample.

The sample is diluted and then directly added to the plasma for the first measurement, which is done using an ICP spectrometer to determine the fine particle fraction. The total metals content is obtained from the second measurement, which uses a particle size independent technique. The big particle fraction, which is predicted to rise under unusual wear situations such filter clogging, contaminant ingestion, or lubricant failure oil, is shown by the difference between these two readings [21].

Early failure detection in oil-lubricated machinery focuses on monitoring lubricant degradation, achieved through continuous measurements or lab analysis of oil samples. The lubricant itself offers valuable insights, like blood tests in human health. Key parameters affecting lubricant condition include temperature, air presence, water content, fuel contamination, and solid particulate matter. Changes in dielectric constant indicate abnormalities, detectable via grid capacitance sensors. Design of experiments (DOE) assesses variables like ferrous particles, water, and SiO_2 contamination, using fractional factorial designs to enhance sensor performance by identifying significant factors [22].

9. Vibration analysis

One method for examining the oscillations and vibrations of machines and buildings is vibration analysis. It involves the measurement and analysis of vibrations to assess the condition of equipment, detect potential faults, and determine the overall health of a system. Vibration analysis is widely employed in various industries, including manufacturing, energy, aerospace, automotive, and more.

Condition monitoring is crucial for maintaining machines by analysing distinct sound and vibration signals from moving parts. This practice involves systematic data collection to detect changes in machine performance, especially variations in vibration signals. Early warnings from condition monitoring enable proactive maintenance, preventing unexpected breakdowns and offering insights into potential failures. It contributes to managing machine life potential, improving maintenance efficiency, and resulting in cost savings by avoiding unplanned downtime and ensuring ongoing machinery reliability. In condition monitoring systems, signal processing techniques are essential for analysing faults based on captured signals. The key methods include time domain analysis, which observes signal changes over time using statistical concepts; frequency domain analysis, examining signal distribution within specific frequency bands; and time-frequency domain analysis, which studies signals simultaneously in both time and frequency domain [23].

Over the last fifty years, technological advancements have significantly propelled the development of condition monitoring and predictive maintenance techniques. These methodologies, encompassing continuous online or periodic offline monitoring of machinery, aim to intelligently guide maintenance decisions by detecting changes in signals indicative of damaged components. The diagnostic process involves mapping between the measurement space and the fault space, focusing on various industrial components, particularly rotary machines like rolling bearings, gearboxes, wind turbines, and more. Vibration emerges as a pivotal diagnostic parameter, extensively employed in condition monitoring for rotary machines due to its effectiveness. Vibration-based techniques, with a reported 90% accuracy in detecting faults, utilize unique vibration signatures associated with specific operating conditions. Four stages usually make up the implementation method: signal processing, vibration measurement and preprocessing, features extraction and selection, and diagnostics.

A bibliographic analysis underscores the significance of vibration-based techniques in detecting diverse faults within rotating machinery, with a chronological organization of literature providing insights into the evolution of condition monitoring research [24]

Conclusion

After the research and study for all the above condition monitoring of vibration analysis, conclude that, Temperature monitoring, vibration monitoring, Oil monitoring and ultrasonic wave monitoring are all come under the smart monitoring, hence which cost low for analysis result and having the complex algorithm which is difficult to apply but advantage, it is possible to used. After that, dynamic monitoring, shock pulse monitoring and acoustic emission are come under the standard monitoring which cost so high, but the software and algorithm are easy to used. Hardware used for the standard monitoring it carried the more electronic devices, but the result gets form the all-standard monitoring techniques is more accurate and carried the less error.

Acknowledgment

We would like to express our truthful gratitude for the chance to explore the field of Machine Fault Detection Using Condition Monitoring Techniques. We sincerely thank all the reviewers, collaborators, and supporters whose knowledge and insights have made this better.

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