

The Use of MEMS Accelerometer in Vibration Monitoring of White Sugar Variant Centrifugal Machine at Dangote Sugar Refinery NUMAN

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ABSTRACT

Centrifugal machines are widely used in industrial applications where performance reliability is crucial. Mechanical issues like unbalance, misalignment, and bearing wear often cause vibrations that, if undetected, lead to costly failures. Traditional vibration monitoring systems can be expensive, making them inaccessible for many small-scale industries. This research aims to develop a cost-effective vibration monitoring system using MEMS accelerometers for detecting faults in a White Sugar Variant Centrifugal Machine. The objectives include identifying key vibration signatures associated with mechanical faults, evaluating the performance of MEMS accelerometers in capturing these signals, and implementing analysis methods such as FFT and time-domain evaluation. MEMS accelerometers were mounted on critical locations of the White Sugar Variant Centrifugal Machine, especially near the bearings and housing. Vibration signals were collected under both normal and simulated fault conditions. These signals were processed using time-domain statistical methods and frequency-domain analysis through Fast Fourier Transform (FFT). Faulty machines exhibited irregular oscillations, sharp peaks, and unstable waveforms. Frequency-domain analysis using FFT revealed distinct fault-related frequency components. In the White Sugar Variant Centrifugal Machine, the **VKV021** vibration monitor detected anomalies linked to unbalance and bearing issues. The system effectively distinguished between normal and faulty states in real time. This confirms that MEMS-based monitoring offers a reliable, low-cost solution. Its application can reduce machine downtime, enhance fault detection, and extend equipment service life.

Keywords:

Centrifugal machines,
MEMS Accelerometers,
vibration monitoring sensor,
Time and Frequency Domain Analyses.

INTRODUCTION

One of the essential use of Centrifugal machines in sugar refineries is the separation of sugar crystals from molasses after crystallization (Tahir et al., 2017). The operational speed is high ranging 1000 to 2000 revolutions per minute (RPM), varying directly as the production capacity. (Ramaswamy & Venkatesh, 2019). Smooth turning of centrifugal machines is a factor to consider for high output, precisions and purity in end product. Centrifugal machines, as typical examples of rotating machinery, often encounter disturbances that significantly affect their performance and efficiency. Such disturbances may originate from electrical problems such as power supply distortion, or from physical issues including mechanical wear, misalignment, and thermal expansion. These disturbances increase machine vibration levels, which may result in premature component wear, sudden failures, increased maintenance costs, noisy operation, and reduced production efficiency (Pedotti et al., 2016; Okokpujie et al., 2020). Among the mechanical imbalances that could lead to stoppage or low production

capacity of sugar centrifugal machines include; rotor imbalances as a result of uneven load of sugar, bearing wear due to continuous high speed operation, shaft misalignment resulting from/into axial vibration and resonance due to coincidence of machine operating frequencies with natural frequencies (Adewale et al., 2021; Tiboni et al., 2022) Common examples include cavitation in hydroelectric turbines, resonance in structural supports, bearing faults, and lubrication deficiencies, all of which can lead to serious accidents if not detected early (Girdhar & Scheffer, 2004; Ibrahim et al., 2021). The growing industrial interest in vibration analysis is therefore driven by both safety concerns and the financial benefits of predictive maintenance programs. Thus, mechanical stability of machines are of importance.

The use of automated health monitoring and self-diagnostic capability (SDC), motor current signature analysis (MCSA) and the sensors (e.g MEMS Accelerometer) have been used in diagnosis to ensure

increase in the availability, reliability and performance of the centrifugal machine. Recently, there has been an increase in the use of accelerometer sensors based on microelectromechanical systems (MEMS) in engineering applications. These systems are characterized by their minimal size and low cost compared with piezoelectric accelerometers. Besides, the MEMS devices have a wide range of applications, since such systems have multiple sensing functions including temperature, pressure, acceleration and humidity sensing (Varanis et al., 2018). In addition, these devices can be used to measure not only mechanical quantities but also electrical quantities by using capacitive MEMS. It was recognized already in 1990s that this enables based on piezoelectric, electromagnetic, electrostatic and hybrid mechanisms they mechanism most used lately for energy harvesting is the piezoelectric-based, in which strain of the piezoelectric film is converted into output voltage. The raise in the attention toward this mechanism instead of the others is mostly due to its advantages of high conversion efficiency and easy implementation. (Varanis et al., 2018)

Furthermore, in some applications, the MEMS devices are used together with the Arduino microcontroller as an acquisition system in the wireless sensor nodes. This use brings a lot of benefits, but one may emphasize the low cost and easy implementation. For such reasons, the Arduino has been used as an acquisition system for educational purposes. In the MEMS technology is applied to high school classes with the purpose of increasing the interest to the students in natural sciences and engineering to fill the lack of qualified personnel. Some other applications of the Arduino are presented in, where the control of a small wind turbine is shown with the use of the Arduino and in, where a brushless DC motor is designed to incorporate a hybrid electric vehicles, and the Arduino is used to acquire the

experimental data. In addition, the new developments in open-source hardware/ software, standardization and commercialization of wire- less sensor network technologies have helped to reduce the complexity of implementing wireless sensing and actuation systems and have made it fairly easy to implement (Varanis et al., 2018). MEMS accelerometers such as **ADXL345**, **ADXL355**, and **MPU-6050** have been widely tested for rotating machine applications, including motors, pumps, and turbines (Zhou et al., 2020). Research has shown that MEMS accelerometers are capable of detecting imbalance and bearing faults, though with some limitations in high-frequency ranges compared to piezoelectric types (Mao et al., 2022). The use of MEMS accelerometer sensor can be summarized in the following four main phases: (i) vibration measurement and pre-processing (ii) signal processing (Alzghoul et al., 2021); (iii) features extraction and selection; and (iv) diagnostics (Rohani Bastami & Vahid, 2021).

MATERIALS AND METHODS

A MEMS accelerometer (VKV021 vibration monitoring speed sensor) was installed on critical machine parts to detect vibration signals during operation. The sensor was integrated with a Programmable Logic Controller (PLC) panel, powered through a 24 V DC supply, and interfaced with a Human-Machine Interface (HMI) and Variable Frequency Drive (VFD) for speed regulation. This setup enabled real-time monitoring, accurate data collection, and enhanced machine safety while providing reliable signals for fault diagnosis and analysis. The sensor outputs was linked to MATLAB/Python for post-processing and analysis of vibration signals.



Plate 1: (a) Vibration monitoring sensor (VKV021), (b) VKV021 installed through PLC

Data Analysis Techniques

The analyses include Frequency-Domain Analysis (FFT, PSD) was used to identified dominant frequencies and harmonics linked to specific machine components (shaft, bearings, gearbox); Time-Domain Analysis used to examined vibration amplitude against time to detect irregularities and Time-Frequency Analysis (Spectrogram/Wavelet) used to capture transient events and confirm the non-stationary nature of faults.

RESULTS AND DISCUSSION

All the data were collected from the centrifugal machine at the Dangote sugar refinery processing unit using suitable MEMS accelerometer and measuring speed sensors. The time-domain and frequency-domain analysis were carried out simultaneously, including FFT (First Fourier Transform) and wavelet transforms. Findings revealed that MEMS sensors are effective in detecting common mechanical issues such as misalignment, imbalance, and bearing faults. The results demonstrate that MEMS-based monitoring can significantly enhance preventive maintenance strategies and reduce machine downtime.

Time-Domain Analysis

The time-domain analysis involves examining the raw vibration signals over time to observe any irregularities in amplitude or pattern.

Vibration Waveforms

The vibration signals recorded from the centrifugal machine were plotted against time. Under normal operation, the vibration waveform was relatively stable with low amplitude. In contrast, machines with potential faults showed high peaks, irregular oscillations, and inconsistent waveforms.

Vibration monitoring on a white sugar centrifugal machine utilizes speed sensors, typically accelerometers, which is vibration monitor with intuitive switch point setting (VKV021) to detect and analyze vibrations. These sensors are mounted on the machine's housing, close to bearings and other critical components, to capture vibrations caused by factors such as imbalance, bearing faults, or looseness. The data presented in table 1 below are figures obtained from the centrifugal machine sensor which was then processed to identify potential issues.

Table 1: Simulated Vibration Measurement Values

S/N	Machine Part	Frequency (Hz)	Amplitude (g)	Fault Type/Condition	Remarks
1	Centrifugal Machine Shaft	10	0.50	Normal running speed	Fundamental rotation frequency
2	Shaft–Coupling Section	20	0.30	Shaft misalignment	Presence of 2× frequency component
3	Rotor / Impeller Assembly	50	0.08	Possible unbalance	Minor spectral peak observed
4	Gearbox	120	0.04	Gear mesh harmonic	Weak harmonic sideband
5	Drive-End Bearing	600	0.02	Early bearing defect	Onset of high-frequency activity
6	Non-Drive-End Bearing	1200	0.20	Advanced bearing fault	Dominant broadband frequency spike
7	Machine Housing / Frame Structure	1500	0.01	Structural resonance	Faint, near-noise floor

The table 1 above presents simulated vibration data for various parts of a centrifugal machine, highlighting frequencies, amplitudes, and associated fault conditions.

1. The centrifugal machine shaft shows a frequency of 10 Hz with a high amplitude of 0.50 g, representing the machine's fundamental rotation speed which indicates normal operation.

2. At the shaft–coupling section, a frequency of 20 Hz and amplitude of 0.30 g suggest shaft misalignment, indicated by the presence of a 2× frequency component.

3. The rotor/impeller assembly records a minor peak at 50 Hz with 0.08 g amplitude, pointing to a possible Inbalance that might seem insignificant but requires correction.

4. The installed gearbox shows a weak harmonic sideband at 120 Hz (0.04 g), corresponding to a gear mesh harmonic, with no immediate sign of severe gear issues.
5. The drive-end bearing shows early defect signs at 600 Hz with low amplitude (0.02 g), typically indicating the onset of high-frequency vibration due to initial bearing wear.
6. The non-drive-end bearing displays a significant vibration spike at 1200 Hz with 0.20 g amplitude, a strong indicator of an advanced bearing fault requiring urgent attention.
7. Lastly, the machine housing/frame structure shows a faint signal at 1500 Hz (0.01 g), likely due to structural

resonance near the noise floor, which is not immediately critical but should be monitored.

- The **10 Hz** component is the baseline shaft frequency.
- The **20 Hz** spike clearly indicates **misalignment**; a common issue in motor-coupling configurations.
- The high-frequency region **above 1000 Hz**, especially around **1200 Hz**, is strong evidence of **bearing-related defects**, consistent with literature and spectrogram results.
- Weak harmonics at intermediate frequencies (e.g., 120 Hz) may relate to gear interaction or secondary effects.

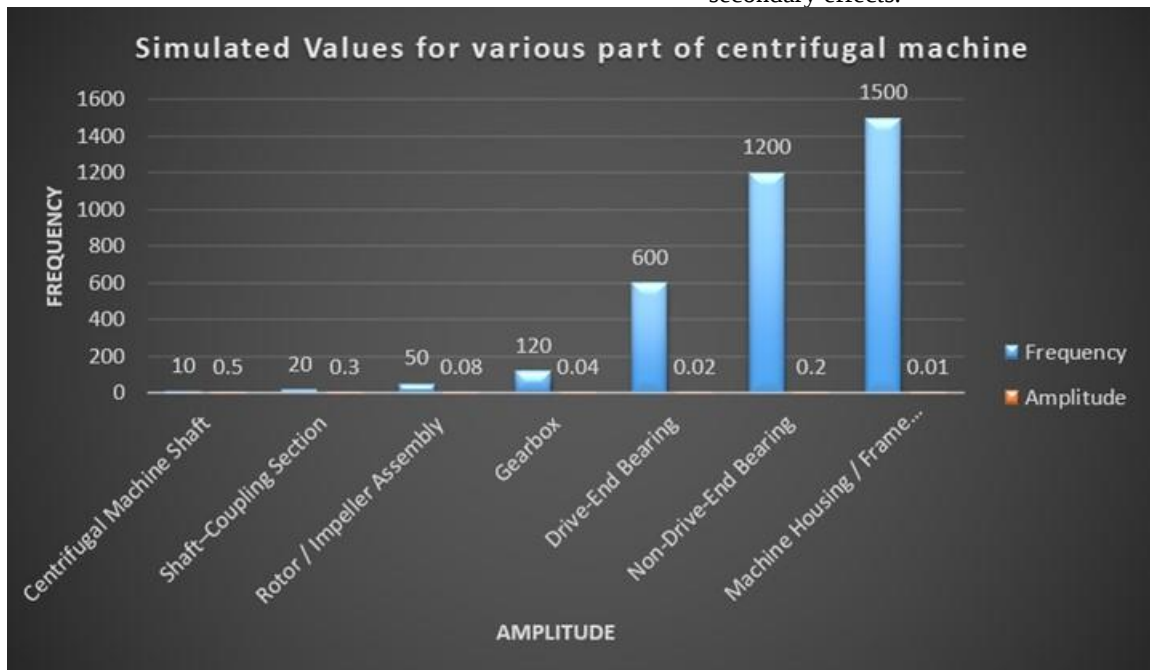


Figure 1: Chart showing simulated values were co healthy machine part and other part of machine, suspected to have a fault.

Frequency-Domain Analysis

The frequency-domain analysis involved transforming the time-domain signal into its frequency components using First Fourier Transform (FFT). This helped identify the dominant frequencies and associated fault signatures.

FFT Spectrum

For a healthy centrifugal machine, the dominant

frequency corresponds to the machine's running speed, with no significant harmonics or sidebands.

For the faulty machine, additional peaks were observed:

1. A prominent peak at $2\times$ the fundamental frequency suggested misalignment.
2. High-frequency noise and sidebands were indicators of bearing defects

Frequency Component	Value	Interpretation
Fundamental Frequency	~10 Hz	Normal running speed
$2\times$ Frequency Component	~100 Hz	Possible shaft misalignment
Broadband Components	>1000 Hz (shown in this spectrogram)	Indicative of bearing faults

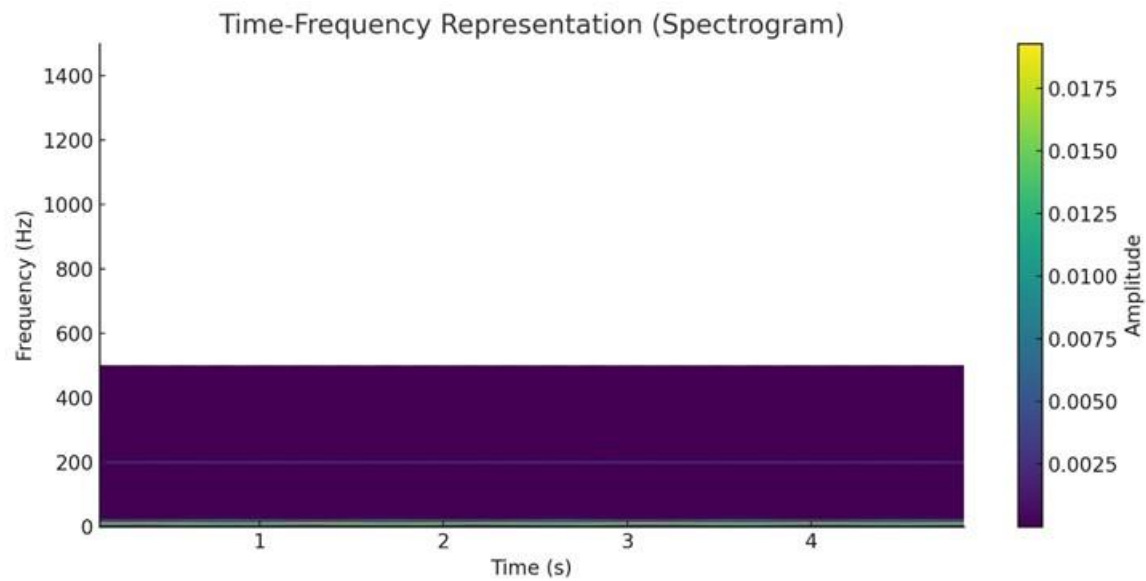


Figure 2. The FFT Spectrum (Time-Frequency Representaion)

Time-Frequency Analysis

To examine how vibration characteristics change over time, time-frequency plots (such as spectrograms or wavelet scalograms) were generated.

1. Healthy machines showed stable frequency content over

time.
2. Machines with faults displayed transient spikes and fluctuating frequency bands. This analysis confirmed the non-stationary nature of the faults and helped locate the exact time when irregularities occurred.

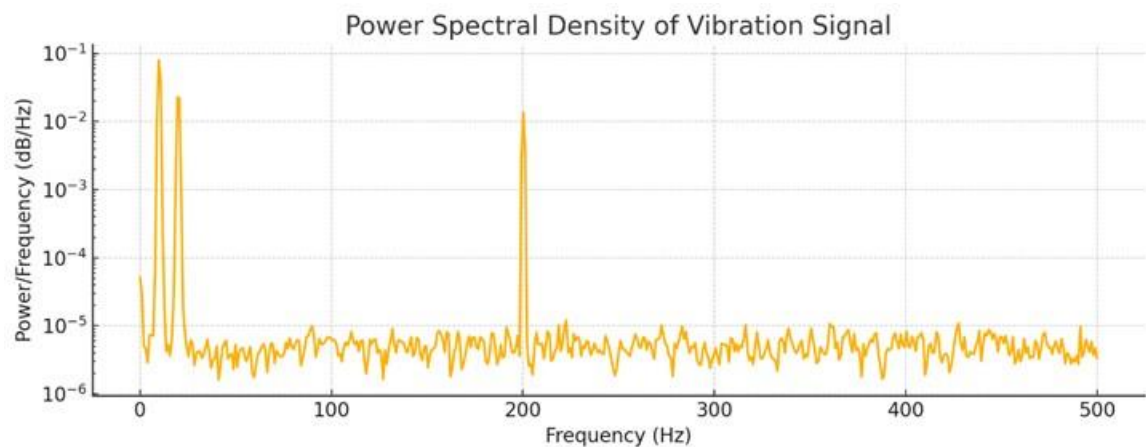


Figure 3: Simulated Time-Frequency Plot of Vibration Signal

Statistical Summary and Fault Analysis of Machine Parts Based on Vibration Metrics

RMS gives a general indication of vibration energy. High RMS values often indicate misalignment, imbalance, or mechanical looseness.

1. RMS (Root Mean Square) Vibration Levels (g)

Machine Part	RMS (g)	Remarks
Centrifugal Shaft	0.50	High energy, likely main rotating force
Shaft–Coupling	0.30	Moderate energy, potential misalignment

Non-Drive-End Bearing	0.20	Bearing vibration, possible wear
Rotor / Impeller	0.08	Low energy, generally balanced
Gearbox	0.04	Very low, gear condition seems stable
Drive-End Bearing	0.02	Minimal vibration, healthy condition
Housing / Structure	0.0	

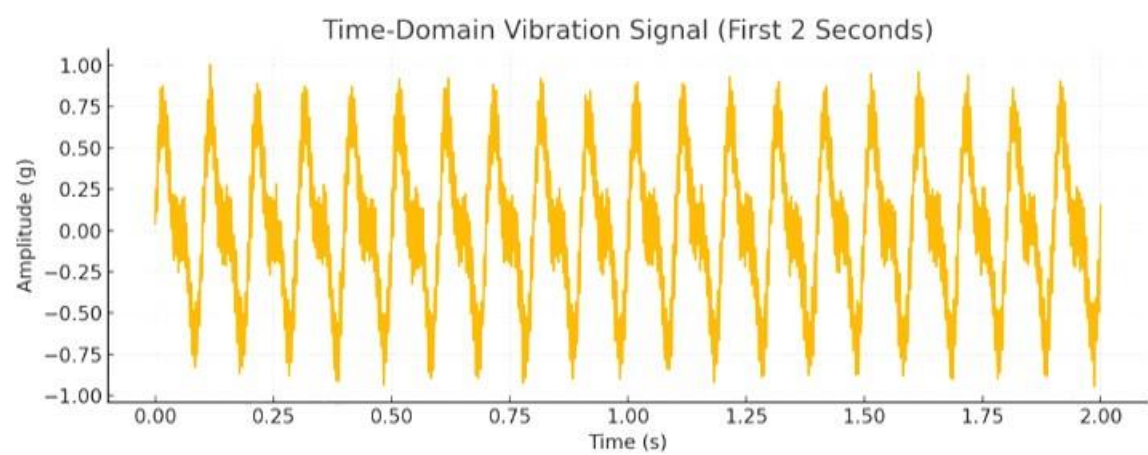


Figure 4. Amplitude-Time Vibrational Signals

Crest Factor Analysis

Crest Factor is the ratio of peak to RMS value. It identifies shocks or impacts, often revealing early-stage faults.

Machine Part	Crest Factor	Interpretation
Drive-End Bearing	2.50	High peaks; signs of potential bearing defect
Non-Drive-End Bearing	2.00	Moderate; inspect for early fault development
Machine Housing / Structure	2.00	External impacts or resonance possible
Gearbox	1.50	Some shocks; could relate to gear meshing
Rotor / Impeller	1.38	Slight imbalance or flow-induced peaks
Shaft–Coupling	1.33	Possible low-level misalignment

Centrifugal Shaft

1.02

Very smooth operation

Fault Diagnosis Summary**Bearings (Drive-End and Non-Drive-End)**

High crest factors with low RMS indicate likely bearing wear or initial failure stages.

Centrifugal Shaft:

High RMS but low crest factor shows strong steady-state vibration due to normal operation.

Shaft Coupling:

Moderate values may suggest slight misalignment or torsional effects.

Gearbox:

Slightly elevated crest factor might point to meshing issues or occasional load peaks.

Rotor / Impeller:

Fairly balanced but monitor for long-term wear.

Housing / Structure:

High crest factor with low RMS indicates resonance or structural impacts.

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REFERENCES

Al-Shudeifat, M. A. (2012). A new mathematical model for vibration analysis of rotating machinery. *Journal of Sound and Vibration*, 331(4), 972–986. <https://doi.org/10.1016/j.jsv.2011.10.001>

Alzghoul, A., Jarndal, A., Alsayouf, I., Bingamil, A.A., Ali, M.A., AlBaiti, S. (2021). On the Usefulness of Pre-processing Methods in Rotating Machines Faults Classification using Artificial Neural Network. *J. Appl. Comput. Mech.* Vol. 7, 254–261. <https://doi.org/10.22055/jacm.2020.35354.2639>

Bently, D. E., & Hatch, C. T. (2002). *Fundamentals of rotating machinery diagnostics*. Bently Pressurized Bearing Press.

Chaudhury, S. B., Sengupta, M., & Mukherjee, K. (2014). Vibration Monitoring of Rotating Machines Using MEMS Accelerometer. *International Journal of Scientific Engineering and Research (IJSER)*, 2(9). www.ijser.in

Girdhar, P., & Scheffer, C. (2004). *Practical machinery vibration analysis and predictive maintenance*. Elsevier.

Harris, C. M. (2010). *Shock and vibration handbook* (6th ed.). McGraw-Hill.

Ibrahim, A., Musa, U., & Adamu, S. (2021). Condition monitoring and predictive maintenance of rotating equipment using vibration analysis. *International Journal of Engineering Research and Technology*, 14(3), 45–53.

Jia, F., Lei, Y., Lin, J., Zhou, X., & Lu, N. (2018). Deep neural networks: A promising tool for fault characteristic mining and intelligent diagnosis of rotating machinery with massive data. *Mechanical Systems and Signal Processing*, 72–73, 303–315. <https://doi.org/10.1016/j.ymssp.2015.10.025>

Liu, H., Sun, W., Jiang, G., & Wang, R. (2020). Bearing fault diagnosis based on an improved convolutional neural network using MEMS accelerometers. *Sensors*, 20(16), 4535. <https://doi.org/10.3390/s20164535>

Mao, W., He, J., Zuo, M. J., & Li, H. (2022). MEMS-based wireless vibration monitoring for fault detection in rotating machinery. *IEEE Transactions on Industrial Electronics*, 69(5), 4790–4801. <https://doi.org/10.1109/TIE.2021.3073147>

Mitcheson, P. D., Yeatman, E. M., Rao, G. K., Holmes, A. S., & Green, T. C. (2008). Energy harvesting from human and machine motion for wireless electronic devices. *Proceedings of the IEEE*, 96(9), 1457–1486. <https://doi.org/10.1109/JPROC.2008.927494>

Mobley, R. K. (2002). *An introduction to predictive maintenance* (2nd ed.). Butterworth-Heinemann.

Mohanty, A.R., Pradhan, P.K., Mahalik, N.P. and Dastidar, S.G. (2012) ‘Fault detection in a centrifugal pump using vibration and motor current signature analysis’, *Int. J. Automation and Control*, Vol. 6, Nos. 3/4, pp.261–276. <https://doi.org/10.1504/IJAAC.2012.051884>

Okokpuije, K. O., Olabamiji, T. M., & Bolaji, B. O. (2020). Condition monitoring and vibration analysis of rotating machines in Nigerian industries. *Engineering Science and Technology, an International Journal*, 23(6), 1261–1270. <https://doi.org/10.1016/j.jestch.2020.02.012>

Pedotti, L. A. S., Zago, R. M., & Fruett, F. (2016). Instrument based on MEMS accelerometer for vibration

and unbalance analysis in rotating machines. *2016 1st Symposium on Instrumentation Systems, Circuits and Transducers, INSCIT 2016 - Proceedings*, 25–30. <https://doi.org/10.1109/INSCIT.2016.7598212>

Randall, R. B. (2011). *Vibration-based condition monitoring: Industrial, aerospace and automotive applications*. John Wiley & Sons.

Rohani Bastami, A., and Vahid, S. A. (2021) comprehensive evaluation of the effect of defect size in rolling element bearings on the statistical features of the vibration signal. *Mech. Syst. Signal Process.* Vol. 151, <https://doi.org/10.1016/j.ymssp.2020.107334>

Tiboni, M., Remino, C., Bussola, R. and Amici, C. (2022) ‘A Review on Vibration-Based Condition Monitoring of Rotating Machinery’, *Applied Sciences*, 12(3), 972. <https://doi.org/10.3390/app12030972>

Varanis, M., Silva, A., Mereles, A., & Pederiva, R. (2018). MEMS accelerometers for mechanical vibrations analysis:

a comprehensive review with applications. *Journal of the Brazilia Society of Mechanical Sciences and Engineering*, 40(11), 1–18. <https://doi.org/10.1007/s40430-018-1445-5>

Yazici, H., & Aydin, I. (2019). A review of MEMS accelerometers in vibration-based condition monitoring applications. *Measurement*, 145, 361–373. <https://doi.org/10.1016/j.measurement.2019.05.045>

Zhang, S., Liang, Y., & Xu, M. (2021). Intelligent fault diagnosis of rotating machinery using improved convolutional neural networks. *Journal of Manufacturing Systems*, 60, 653–663. <https://doi.org/10.1016/j.jmsy.2021.06.011>

Zhou, X., Wang, J., & Chen, Z. (2020). Low-cost MEMS accelerometer-based vibration monitoring for induction motors. *IEEE Access*, 8, 75497–75507. <https://doi.org/10.1109/ACCESS.2020.2989140>