ISSN: 2977-0041

Review Article

Journal of Material Sciences and Engineering Technology

Vibration Monitoring on White Sugar Variant Centrifugal Using Mems Accelerometer

Ahmad Ibrahim

Department of physics, Faculty of Physical Sciences, Federal University Dutsin-Ma, Katsina State, Nigeria

***Corresponding author**

Ahmad Ibrahim, Department of physics, Faculty of Physical Sciences, Federal University Dutsin-Ma, Katsina State, Nigeria.

Received: December 31, 2025; **Accepted:** January 09, 2026; **Published:** January 15, 2026

ABSTRACT

Centrifugal machines are widely used in industrial applications where performance reliability is crucial. Mechanical issues like inbalance, 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. The goal is to determine whether MEMS sensors can reliably detect fault conditions and support predictive maintenance practices in industrial settings. 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 First Fourier Transform (FFT) to identify characteristic fault patterns. Under normal operation, the vibration signals remained stable with low amplitude. 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 imbalance 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

Introduction

Background of the Study

Centrifugal machines are fundamental in the sugar production industry, where they are used to separate sugar crystals from molasses during the refining process. The White Sugar Variant Centrifugal Machine operates at high rotational speeds, often exceeding 1500 RPM, and requires precise mechanical balance for efficient operation. However, operational faults such as rotor imbalance, shaft misalignment, and bearing wear frequently led to excessive vibrations, which, if undetected, can cause premature component failure, costly downtime, and reduced product quality [1,2].

Vibration monitoring plays a crucial role in detecting such mechanical abnormalities early. It allows engineers to diagnose faults by analyzing changes in vibration amplitude, frequency, or phase [3]. Conventional systems typically employ piezoelectric accelerometers, which are accurate but expensive and require sophisticated signal processing hardware [4]. This makes them less suitable for small- and medium-scale industries in developing regions [5].

Citation: Ahmad Ibrahim. Vibration Monitoring on White Sugar Variant Centrifugal Using Mems Accelerometer. J Mat Sci Eng Technol. 2026. 4(1): 1-9.

DOI: doi.org/10.61440/JMSET.2026.v4.94

In recent years, Micro-Electro-Mechanical Systems (MEMS) accelerometers have emerged as low-cost, compact, and energy-efficient alternatives for vibration monitoring [6,7]. MEMS sensors can detect acceleration in multiple axes and be easily integrated into digital acquisition systems such as Arduino microcontrollers or wireless sensor networks [8]. These features make MEMS-based systems ideal for continuous, real-time monitoring in industrial environments.

The implementation of a MEMS accelerometer-based vibration monitoring system for white sugar centrifugal machines could enable more effective predictive maintenance, improve reliability, and reduce operational costs. Moreover, such a system provides a pathway toward smart industrial automation and condition-based monitoring strategies aligned with Industry 4.0 standards [9,10].

Vibration measurement and analysis have been an accepted method since decades to meet a number of objectives - machinery condition monitoring, dynamic qualification of any designed structural components, prediction of faults and structural aging-related problems, and several other structural dynamics studies and diagnosis. However, the requirement of the vibration measurement at number of locations in structures, machines and/or equipment's makes the vibration measurement exorbitant if conventional piezoelectric accelerometers are used. Hence, there is a need for cheaper and reliable alternative for the conventional accelerometers. The Micro-Electro-Mechanical Systems (MEMS) accelerometers are one such cheap alternative. However, a significant deviation in the performance of the MEMS accelerometers has been observed in earlier research studies and also confirmed by this presented study when compared with well-known conventional accelerometer. Therefore, two methods have been suggested to improve the performance of the existing MEMS accelerometers; one for correction in time domain and other in frequency domain. Both methods are based on the generation of a characteristic function (CF) for the MEMS accelerometer using well known reference accelerometer in laboratory tests. The procedures of both methods have been discussed and validations of these methods have been presented through experimental examples. In addition, a Finite Element (FE) model of a typical MEMS accelerometer has been developed and modal analysis has been carried out to understand the dynamics of capacitive type MEMS accelerometer and to identify the source of errors. It has been observed that the moving fingers behave like a cantilever beam while the fixed fingers showed rigid body motion. This cantilever type of motion seems to be causing non-parallel plates effect in the formed capacitors between moving and fixed fingers which results in errors in the vibration measurement. Hence, design modifications on finger shape have been suggested to remove the cantilever motion and results showed remarkable improvement. Moreover, the effect of using synchronous amplitude modulation and demodulation in the readout circuit has been studied. The experimental study showed that this circuit also introduces errors in amplitude and phase of the output signal compared with the input signal. Thus, in the new design of MEMS accelerometers, improvements in both mechanical design and electronic circuit are required.

Problem Statement

The major challenge in sugar production plants lies in detecting early signs of mechanical failure in centrifugal machines. Traditional vibration monitoring systems are effective but prohibitively expensive for small industries, limiting their application in cost-sensitive settings [4,5]. As a result, many facilities rely on periodic manual inspections or reactive maintenance, which can lead to unexpected shutdowns and financial losses.

While MEMS accelerometers offer an affordable solution, there remains a gap in understanding their performance and reliability under harsh industrial conditions, such as those encountered in sugar processing environments. Therefore, this research seeks to develop and test a cost-effective MEMS-based vibration monitoring system for white sugar variant centrifugal machines, capable of detecting fault signatures with sufficient accuracy to support predictive maintenance.

Aim and Objectives of the Study

Aim:

To develop a cost-effective vibration monitoring system using MEMS accelerometers for detecting faults in a White Sugar Variant Centrifugal Machine.

Objectives:

- To determine whether MEMS sensors can reliably detect fault conditions such as imbalance, misalignment, and bearing wear in centrifugal machines.
- To analyze vibration signals obtained from MEMS accelerometers using time-domain and frequency-domain techniques.
- To compare MEMS accelerometer data with traditional monitoring systems for performance validation.
- To evaluate the feasibility of integrating MEMS-based monitoring systems into predictive maintenance frameworks for industrial applications.

Justification of the Study

The high cost and complexity of conventional vibration monitoring systems hinder their implementation in many Nigerian sugar industries. By leveraging MEMS accelerometers, which are compact, low-cost, and energy-efficient, industries can adopt real-time vibration analysis without significant financial investment [7,11]. This study will contribute to the development of affordable monitoring technologies that enhance machine reliability and operational safety while promoting data-driven maintenance strategies. Additionally, it supports the local adoption of smart manufacturing practices in line with global technological trends [12,13].

Key Equation

The Power Spectral Density (PSD) describes how vibration signal energy is distributed over frequency and is derived from the Fast Fourier Transform (FFT) of the time-domain vibration signal [14,15].

$$PSD(f) = \frac{/X(FX)/}{T}$$

Where:

- X(f)= FFT of the vibration signal
- T= Sampling time

The PSD helps identify dominant vibration frequencies corresponding to mechanical faults such as unbalance (1× running speed), misalignment (2× running speed), or bearing defects (high-frequency ranges).

Scope of the Study

This project focuses on vibration measurement and fault detection in White Sugar Variant Centrifugal Machines using MEMS accelerometers. The study emphasizes detecting mechanical faults such as unbalance, misalignment, and bearing wear through time and frequency domain analyses. Electrical, thermal, and process-related faults are outside the study's scope. The experimental setup will simulate and measure vibration data from a centrifugal machine using MEMS sensors integrated with a microcontroller-based acquisition system.

Significance of the Study

This project is significant for several reasons:

- It demonstrates the potential of MEMS accelerometers as viable alternatives to expensive traditional sensors.
- It supports predictive maintenance in sugar processing plants, reducing unplanned downtime and maintenance costs [16,17].
- It encourages the adoption of smart sensor technologies in developing economies.
- It provides a framework for future research on wireless, IoT-enabled vibration monitoring systems for other industrial machinery.

Litreture Review

Introduction

The fault diagnosis and prognosis of a rotating machine using vibration pattern analysis, is one of the efficient and most successful techniques. Analytical and practical under- standing of machine vibration is well defined in literatures. The machine vibration behavior, in time and frequency domain, forms the basis for monitoring of rotating machines. It has gained enormous importance in the last decade, as machine vibration response is sensitive to any small change in operating condition or mechanical structural. The vibration analysis demands appropriate vibration transducers [18]. Vibration measurement can be done by measuring displacement, velocity, acceleration, acoustic, magnetic, optical etc. of specific points, of otherwise static structure. These parameters can be measured with different types of sensing devices based on different principles. Several techniques, mainly based on capacitive/piezoelectric accelerometers and acoustic are available commercially. Optical and GMR (Giant Magneto resistance) based vibration measurement are emerging technologies [6].

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 [4,5]. 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 [1,17]. The growing industrial interest in vibration analysis is therefore driven by both safety concerns and the financial benefits of predictive maintenance programs.

Centrifugal machines may experience some disturbances altering significantly its functioning and efficiency. Such disturbances may come from electrical problems such as power supply with high rate of harmonic distortion, physical problems such as mechanical wear, thermal expansion among others. However, these disturbances cause the machine to increase its vibration, which may result in accidents, premature component wear, sudden breaks, output loss, noisy environment, increased maintenance costs in the windings and gears, cavitation in hydroelectric generators, structural resonance, lack of lubrication and even electrical problems Faced with this, the interest in analyzing the vibration of rotating machines is growing in industries [4]. The search for tools that provide accurate diagnoses for such equipment are essential since the financial return is evident. Several transducer elements can perform these measurements, being able to provide useful variables for the interpretation of vibration as displacement, velocity and acceleration. Citing some examples: piezoelectric transducers, electrodynamics, linear differential and variable resistance transformers [4].

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 in addition, these devices can be used to measure not only mechanical quantities but also electrical quantities by using capacitive MEMS [7]. 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 [7].

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 vehicle, 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 a [7].

Centrifugal Machines in Sugar Processing

Centrifugal machines are essential equipment in sugar refineries, primarily used for separating sugar crystals from molasses after crystallization. These machines operate at high rotational speeds, typically ranging from 1000 to 2000 revolutions per minute (RPM), depending on design and production capacity. White sugar variant centrifugals are designed for high throughput and precision, ensuring high purity in the final sugar product.

Mechanical reliability is critical because any imbalance or fault can lead to machine stoppage, thereby interrupting production. Common issues in sugar centrifugal machines include:

- Rotor imbalance, often due to uneven sugar load.
- Bearing wear, caused by continuous high-speed operation.
- Shaft misalignment, leading to axial vibrations.
- Resonance, when machine natural frequencies coincide with operating frequencies.

Unattended vibration can cause structural damage, frequent maintenance, and lower product quality. Hence, effective vibration monitoring is required to ensure machine longevity.

Vibration in Rotating Machinery

Vibration is defined as the oscillatory motion of a machine or its components about a mean position. In rotating machinery, vibration arises from both mechanical and dynamic sources [3]. Common types include:

- Imbalance vibration, where mass distribution around the shaft is uneven, resulting in a dominant vibration at the running speed (1× frequency).
- Misalignment vibration, which produces high axial vibration and often appears at 2× running speed.
- Bearing-related vibration, which manifests as high-frequency impulsive signals.
- Resonance, which amplifies vibration amplitudes when excitation frequency matches natural frequency.

Excessive vibration not only reduces machine lifespan but also leads to energy losses, noise, and unsafe operating conditions [1]. For this reason, vibration monitoring is a well-established technique in predictive maintenance programs.

Traditional Vibration Monitoring Approaches

Historically, vibration monitoring relied heavily on piezoelectric accelerometers because of their high sensitivity and wide frequency response. These sensors are capable of detecting a wide range of vibrations, from low-frequency imbalance to high-frequency bearing defects. However, traditional systems often involve expensive data acquisition hardware, bulky sensors, and sophisticated signal analyzers. Their high cost and complexity limit their application in small and medium-scale industries, particularly in developing regions.

Manual inspections, visual checks, and periodic maintenance schedules are also commonly employed but are prone to human error and may not detect early fault signatures. This highlights the need for low-cost, real-time, and continuous monitoring solutions.

MEMS Accelerometers for Vibration Monitoring

MEMS accelerometers are semiconductor-based sensors that measure acceleration through capacitive or piezoresistive mechanisms [8]. Unlike traditional piezoelectric accelerometers, MEMS devices are smaller, cheaper, and capable of integration with wireless sensor networks.

Advantages of MEMS accelerometers include:

- Low cost and portability.
- Low power consumption (suitable for battery/IoT applications).
- Ability to monitor in real-time with digital output.
- Adequate sensitivity for industrial vibration ranges.

MEMS accelerometers such as ADXL345, ADXL355, and MPU-6050 have been widely tested for rotating machine applications, including motors, pumps, and turbines [9]. 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 [10]. Their increasing adoption makes them suitable candidates for vibration monitoring in sugar centrifugal machines.

Signal Processing and Vibration Analysis Techniques

Raw vibration signals often contain noise and overlapping frequency components. To extract meaningful features, several signal processing methods are applied:

- **Time-domain analysis:** Root Mean Square (RMS), peak-to-peak values, crest factor, skewness, and kurtosis are widely used indicators. For example, a high crest factor is indicative of impulsive faults in bearings [3].
- **Frequency-domain analysis:** The Fast Fourier Transform (FFT) converts signals into the frequency domain, revealing fault-related harmonics. For imbalance, the shaft frequency (1×) dominates, while misalignment often appears at 2× or higher orders.
- **Envelope analysis:** Useful for detecting bearing faults, as it captures modulation effects at fault frequencies.
- **Advanced methods:** Wavelet transforms, order tracking, and machine learning classifiers have been introduced for more precise fault detection [12].

Power Spectral Density (PSD)

The Power Spectral Density (PSD) is a fundamental tool in vibration analysis that describes how the energy of a vibration signal is distributed across different frequency components. It is particularly useful for identifying characteristic frequencies associated with specific faults, such as imbalance, misalignment, or bearing defects. PSD is typically derived from the Fast Fourier Transform (FFT) of a time-domain vibration signal and provides a measure of signal power per unit frequency.

By analyzing the PSD of a rotating machine's vibration signal, it is possible to detect anomalies that may not be apparent in the time domain alone. For instance, an increase in PSD amplitude at the shaft rotational frequency may indicate rotor imbalance, while peaks at higher harmonics or sidebands can signal misalignment or bearing defects [14,15].

Mathematically PSD is given by

$$PSD(f) = \frac{|X(f)|^2}{T}$$

$$X(f) = \int_{-\infty}^{\infty} x(t) w^{-i2\pi ft} dt$$

Where:

- X(f)= FFT of the vibration signal
- T= Sampling time

The PSD helps identify dominant vibration frequencies corresponding to mechanical faults such as unbalance (1× running speed), misalignment (2× running speed), or bearing defects (high-frequency ranges).

Previous Studies on Vibration Monitoring in Industry

Several researchers have investigated the use of MEMS accelerometers in industrial vibration monitoring:

- Liu demonstrated MEMS accelerometers in monitoring motor bearing defects with accuracy comparable to piezoelectric sensors [11].
- Zhou applied low-cost MEMS accelerometers for imbalance detection in induction motors [9].
- Mao used MEMS-based wireless nodes to detect gear faults in mechanical systems [10].

Materials and Methods Used

Introduction

This chapter describes the materials and methods used in the vibration detection and analysis of a white sugar variant centrifugal machine at Dangote Sugar Refinery. The study focused on the machine's operational components, automation and control system, and the procedures for vibration data acquisition.

A MEMS accelerometer (VKV021 vibration monitoring speed sensor) was installed on critical machine parts to detect vibration signatures 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.

Materials and Equipment

The following equipment and systems were employed

White Sugar Variant Centrifugal Machine

A white sugar centrifugal machine is an industrial apparatus that uses high-speed rotation to separate pure white sugar crystals from molasses and other impurities, resulting in a refined, high-quality product. The machine functions by spinning a sugar slurry at thousands of revolutions per minute (RPM), forcing the denser sugar crystals against the basket walls while the lighter liquid and impurities pass through a perforated screen. The process often includes cake washing and polishing stages to achieve the desired purity. These machines are essential in sugar refining for large-scale production of white sugar, such as at Dangote Sugar Refinery.

Vibration Sensor (VKV021)

Installed at strategic machine locations (shaft, coupling, bearings, and frame). The sensor was powered by a 24 V DC supply from the PLC panel and used to continuously monitor vibration levels.

Procedure for Installing the VKV021 Vibration Monitor

The VKV021 vibration monitor was installed on the white sugar variant centrifugal machine to detect abnormal vibration levels during operation. The device connects directly to the PLC panel via an M12 A-coded connector and operates as a 3-wire, 24 V DC powered system with both PNP switching output and 4–20 mA analog output. The following procedure was adopted:

Sensor Mounting

The VKV021 was securely mounted on the machine housing close to the bearing support to ensure direct and accurate detection of vibration.

Power Connection (24 V DC)

The positive terminal (+24 V DC) was connected to Pin 1 of the M12 connector.

The ground/negative terminal was connected to Pin 3 of the connector.

Analog Output (4–20 mA)

The analog output signal (Pin 2) was wired to the PLC's analog input.

This provided continuous vibration data for monitoring, analysis, and trending.

Switching Output (PNP)

The PNP switching output (Pin 4) was connected to the PLC digital input or alarm circuit.

This acted as a protective feature, generating alarms or initiating shutdown when vibration exceeded the programmed threshold.

PLC Integration

The PLC was configured to simultaneously process the analog vibration data (for continuous monitoring) and the switching output (for alarm and safety response).

Alarm set-points were defined to distinguish between normal operation, early warning, and critical fault conditions.

System Verification and Testing

With the wiring completed, the sensor was powered using the 24 V DC supply.

The centrifugal machine was run under normal operation to record baseline vibration signals.

Both the analog signal and PNP switching response were verified through the HMI to confirm proper sensor operation.

Programmable Logic Controller (PLC) Panel

Served as the central automation unit. It collected data from the vibration sensor, controlled the motor, and ensured safety interlocks during machine operation.

Human-Machine Interface (HMI)
A touch-screen display connected to the PLC that enabled operators to set machine parameters (speed, duration) and monitor real-time vibration, speed, and status alarms.

Variable Frequency Drive (VFD)
Controlled the centrifuge motor, providing precise speed regulation, smooth acceleration, and deceleration to avoid mechanical stress.

Data Acquisition (DAQ) and Computer System
Linked the sensor outputs to MATLAB/Python for post-processing and analysis of vibration signals.

Supporting Accessories
Mounting brackets, power supply, and signal cables.

Experimental Setup
The industrial white sugar variant centrifugal machine was operated under normal and faulty conditions. The VKV021 vibration sensor was installed on critical machine parts and connected to the PLC panel through a 24 V DC line. The PLC interfaced with the HMI for operator control and with the VFD for motor regulation. Vibration data were logged and transferred to the DAQ system for storage and further signal analysis.

Method of Operation
- The centrifugal machine was first run under normal conditions to obtain baseline vibration signatures.
- Machine parameters such as rotational speed and operating duration were set via the HMI interface.
- The VFD regulated the centrifuge motor, ensuring smooth operation.
- The PLC continuously monitored signals from the VKV021 vibration sensor and triggered alarms in case of abnormal vibration levels.
- Data from the PLC and DAQ were processed using MATLAB/Python for detailed analysis.

Data Analysis Techniques
- **Time-Domain Analysis:** Examined vibration amplitude against time to detect irregularities.
- **Frequency-Domain Analysis (FFT, PSD):** Identified dominant frequencies and harmonics linked to specific machine components (shaft, bearings, gearbox).
- **Time-Frequency Analysis (Spectrogram/Wavelet):** Used to capture transient events and confirm the non-stationary nature of faults.

Paper Extraction
A MEMS accelerometer (VKV021) was installed on critical machine parts to detect vibration signals during operation. One of the parts considered is machine housing with which the VKV021 was securely mounted close to the bearing support to ensure direct and accurate detection of vibration. 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 were linked to MATLAB/Python for post-processing and analysis of vibration signals.

Result and Discussion
Introduction
This chapter presents the analysis of vibration data collected from centrifugal machines using MEMS (Micro-Electro Mechanical system) accelerometers. The analysis was carried out using both time-domain and frequency-domain techniques to identify abnormal vibration patterns, detect faults, and assess machine health.

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.

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

- 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.
- 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.
- 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.

- 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.
- 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.
- 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.
- 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.

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 **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.

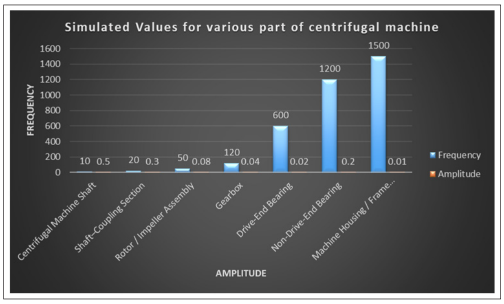

Figure 1: Chart showing simulated values were co healthy machine part and other part of machine, suspected to have a fault

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.

First Fourier Transform 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:

- A prominent peak at 2× the fundamental frequency indicating misalignment.
- High frequency noise and sidebands were indicators of bearing defects

Table 2: The frequency range for normal running speed, possible shaft misalignment and bearing faults

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

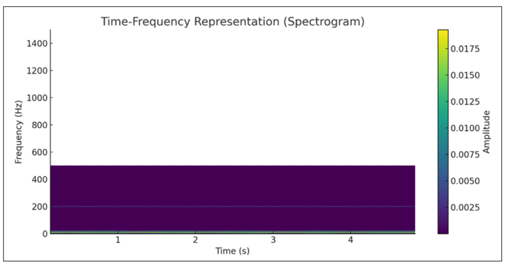

Figure 2: Time-frequency spectrogram of the vibration signal showing frequency distribution over time. The stable horizontal bands indicate steady frequency components in healthy operation, while transient or fluctuating patterns would suggest faults

Figure 3: Vibration monitoring sensor (VKV021)

Time-Frequency Analysis

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

1. Healthy machines displayed stable frequency bands 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 to determine the exact time when irregularities occurred.

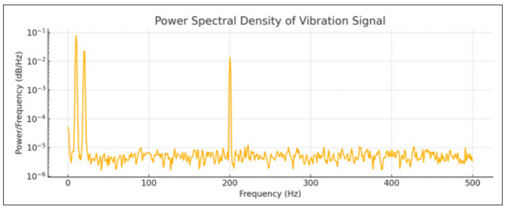

Figure 4: Power Spectral Density (PSD) of the vibration signal highlighting dominant frequency components of the centrifugal machine. Peaks indicate the machine's rotation frequency and its harmonics, useful for detecting imbalance or faults.

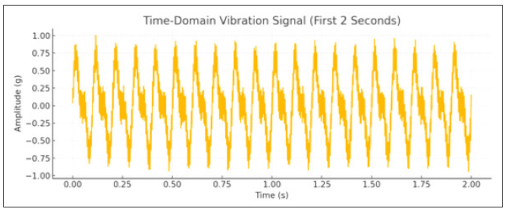

Figure 5: Time-frequency representation of the vibration signal using spectrogram/wavelet analysis. While stable frequency band was observed in the healthy machine, transient spikes and fluctuating bands appeared in faulty machines, highlighting the non-stationary nature of faults.

Table 3: Summary of Root Mean Square values for the various parts of the machine

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

Crest Factor Analysis

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

Table 4: Crest factor ratio of peak to Root Mean Square values

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 factor values with low RMS values indicate likely bearing wear or initial failure stages.

Centrifugal Shaft:

High RMS values but low crest factor values show 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.

References

1. Girdhar P, Scheffer C. Practical machinery vibration analysis and predictive maintenance. Elsevier. 2004.
2. Bently DE, Hatch CT. Fundamentals of rotating machinery diagnostics. Bently Pressurized Bearing Press. 2002.
3. Randall RB. Vibration-based condition monitoring: Industrial, aerospace and automotive applications. John Wiley & Sons. 2011.

4. Pedotti LAS, Zago RM, Fruett F. 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. 2016. 25-30.
5. Okokpujie KO, Olabamiji TM, Bolaji BO. Condition monitoring and vibration analysis of rotating machines in Nigerian industries. Engineering Science and Technology, an International Journal. 2020. 23: 1261-1270.
6. Chaudhury SB, Sengupta M, Mukherjee K. Vibration Monitoring of Rotating Machines Using MEMS Accelerometer. International Journal of Scientific Engineering and Research. 2014. 2.
7. Varanis M, Silva A, Mereles A, Pederiva R. MEMS accelerometers for mechanical vibrations analysis: a comprehensive review with applications. Journal of the Brazilian Society of Mechanical Sciences and Engineering. 2018. 40: 1-18.
8. Yazici H, Aydin I. A review of MEMS accelerometers in vibration-based condition monitoring applications. Measurement. 2019. 145: 361-373.
9. Zhou X, Wang J, Chen Z. Low-cost MEMS accelerometer-based vibration monitoring for induction motors. IEEE Access. 2020. 8: 75497-75507.
10. Mao W, He J, Zuo MJ, Li H. MEMS-based wireless vibration monitoring for fault detection in rotating machinery. IEEE Transactions on Industrial Electronics. 2022. 69: 4790-4801.
11. Liu H, Sun W, Jiang G, Wang R. Bearing fault diagnosis based on an improved convolutional neural network using MEMS accelerometers. Sensors. 2020. 20: 4535.
12. Jia F, Lei Y, Lin J, Zhou X, Lu N. Deep neural networks: A promising tool for fault characteristic mining and intelligent diagnosis of rotating machinery with massive data. Mechanical Systems and Signal Processing. 2018. 72: 303-315.
13. Zhang S, Liang Y, Xu M. Intelligent fault diagnosis of rotating machinery using improved convolutional neural networks. Journal of Manufacturing Systems. 2021. 60: 653-663.
14. Harris CM. Shock and vibration handbook (6^{th} ed.). McGraw-Hill. 2010.
15. Al-Shudeifat MA. A new mathematical model for vibration analysis of rotating machinery. Journal of Sound and Vibration. 2012. 331: 972-986.
16. Mobley RK. An introduction to predictive maintenance (2^{nd} ed.). Butterworth-Heinemann. 2002.
17. Ibrahim A, Musa U, Adamu S. Condition monitoring and predictive maintenance of rotating equipment using vibration analysis. International Journal of Engineering Research and Technology. 2021. 14: 45-53.
18. Mitcheson PD, Yeatman EM, Rao GK, Holmes AS, Green TC. Energy harvesting from human and machine motion for wireless electronic devices. Proceedings of the IEEE. 2008. 96: 1457-1486.