

Measurement of Vibration Signals of Rotating Machinery Based on FFT Spectrum

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Abstract—The aim of the research is to provide information about changes in vibration dynamics, especially at high frequencies. The method is providing the measurement installation from mini rotary engine with Arduino UNO and accelerometer to record the raw data from serial monitor in varied rotation of shaft. The result is the acceleration of a shaft due to an attached mass depends directly on the distance of the mass from the shaft center. The farther the load is placed, the greater the acceleration amplitude observed over time, while the oscillation frequency is governed by the shaft's rotational speed. There is an interesting result, the highest vibration acceleration was obtained at the y_1 axis. Therefore, y_1 is the best position to determine the characteristics of rotary engine. By combining these parameters, it is possible to evaluate the stability, detect potential faults, and assess the health of rotating machinery or structural components.

Keywords—*arduino UNO; acceleration; shaft; axis; structural components*

I. INTRODUCTION

The shaft in a rotary engine machine is one of the most critical components because it transfers rotational energy from the driving motor to the connected load. When additional mass is attached to the shaft—whether in the form of couplings, gears, rotors, or testing loads—the system's dynamic behavior changes significantly. The extra mass introduces both static and dynamic forces that influence how the shaft vibrates during operation.

Vibration in a shaft arises primarily due to unbalance, misalignment, or resonance conditions [1] and [2]. When a mass is mounted on the shaft, it shifts the center of gravity away from the true rotational axis. This creates centrifugal forces that act outward with each revolution, causing the shaft to bend or oscillate. The heavier or farther the mass is located from the center, the greater the force, and consequently, the higher the vibration amplitude.

As the rotational speed increases, these vibrations may follow a predictable pattern. At lower speeds, the shaft may show small, almost negligible deflections. However, as the speed approaches the natural frequency of the shaft-mass system, resonance can occur. At resonance, even a small unbalance force can produce large vibrations, potentially leading to fatigue, excessive wear, or even failure of bearings and couplings [3].

The amount of vibration energy present at each specific frequency in a complex vibration signal generating Power Spectral Density (PSD) that is helping engineers understand random vibration by quantifying its power distribution across a frequency spectrum by Fast Fourier Transform (FFT). It converts a time-domain signal into the frequency domain, decomposing it into its sinusoidal components. From here, the PSD is derived, showing how much power is contained within each frequency interval. Engineers rely on this representation because it provides a clear and quantitative measure of signal

behavior, particularly in complex or noisy systems [4], [5] and [6].

The Root mean square (RMS) over time can be visualized as a continuous story of machine behavior. At the beginning of operation, the RMS value may start low as the system stabilizes. Over time, small fluctuations in RMS reflect the natural dynamic response of the machine [7] and [8]. However, any significant upward trend signals an increase in vibration energy, often preceding a mechanical fault. By monitoring this progression, maintenance teams can anticipate failures and schedule preventive interventions, reducing unexpected downtime [9].

Therefore, in this research the vibration of rotated shaft in mini rotary engine is evaluated by investigating the vibration parameter values to gain a clear understanding of the dynamic behavior of a system or machine when it is subjected to operating conditions [10]. By measuring and analyzing vibration characteristics such as amplitude, frequency, acceleration, RMS values, and PSD, engineers can identify abnormalities such as imbalance, misalignment, looseness, or bearing wear in rotating machinery. Detecting these early prevents unexpected breakdowns and costly downtime.

II. LITERATURE REVIEW

There are three vibration parameters which can be used to express the magnitude of vibration: displacement, velocity, and acceleration. To find the amplitude from a simple harmonic motion equation, identify the coefficient of the cosine function in the simple harmonic motion equation. The absolute value of this coefficient is the amplitude. The total distance traveled in one complete cycle as it oscillates, multiplying the amplitude. In the sense of simple harmonic motion, an object that moves back and forth over the same path is in a periodic motion. This is caused by a restoring force that acts to bring the moving object to its equilibrium position. A simple harmonic motion occurs when the restoring force is proportional to the displacement of an object.

Where x is the amplitude, A is the displacement, ω is the angular velocity, t is the time, and a is the acceleration, the calculation formulas for the vibration parameters are shown in the following equations.

$$x = A \sin \omega t \quad (1)$$

$$v = \omega A \cos \omega t \quad (2)$$

$$a = -\omega^2 A \sin \omega t \quad (3)$$

Vibration signals measured from rotating machinery, structures, or vehicles often contain multiple frequency components arising from unbalance, misalignment, bearing defects, or external excitation. Analyzing these signals solely in the time domain can obscure important details. Spectral analysis, typically achieved through the FFT, reveals the relationship between amplitude and frequency, enabling precise identification of dominant modes and fault signatures. This spectrum highlights how energy is distributed across frequencies, making it possible to identify resonances and harmonics. When an FFT analyzer generates frequency-domain data, the output is a frequency spectrum. This spectrum is typically extracted in the form of a power spectrum and a cross-power spectrum.

A common mathematical equation used in vibration analysis with FFT is to obtain the amplitude, frequency, and RMS of an acceleration signal $a(t)$. If a discrete signal $a(n)$ consists of N points with a sampling interval Δt , then the FFT is defined as:

$$X[k] = \sum_{n=0}^{N-1} a[n] e^{-j\frac{2\pi}{N}kn} \quad (4)$$

$k=0, 1, \dots, N-1$ ((frequency index),

$X[k]$ = complex spectrum.

The vibration amplitude from the spectrum is calculated using:

$$A[k] = \frac{2}{N} |X[k]| \quad (5)$$

The factor $2/N$ is used to match the amplitude to the original signal (single-sided spectrum). If $x(t)$ is a vibration signal (displacement, velocity, or acceleration), then the RMS is calculated from the spectrum.

$$x_{rms} = \sqrt{\frac{1}{2} \sum_{k=1}^{N/2} A[k]^2} \quad (6)$$

III. METHODOLOGY

A. Tools and Materials

The main tools and materials used in this study consist of:

1) Hardware includes ADXL345 accelerometer sensor, Arduino Uno R3, 2x16 LCD character display, transformer, and other components.

2) Software includes Arduino Integrated Development Environment (IDE), Megunolink, and PCB Wizard.

B. Experiment Setup

All of the accelerometer sensors measured the vibration on the rotary mini engine across the x -, y -, and z -axis, over bearing housing. The vibration signals were then compared between the three sensors and analyzed by extracting the signal features in time and frequency domains. Two sensors were examined based on loaded shaft different cases. All sensors demonstrated a significant difference between different distance of loaded shaft. Based on the empirical results, this paper finally proposes the best axis position for vibration measurement.

C. Testing Procedure

The test was conducted by preparing a small-scale rotary shaft tester. The device consisted of an on-off switch, a 120-volt DC mini dynamo motor, a flexible coupling transmission, bearings, and a shaft. Shaft rotation was measured using a speed sensor on the dynamo, while vibration sensors were measured using an Arduino UNO circuit and accelerometers mounted at two bearing housing positions. The measurement results were read on a laptop's serial monitor. During the test, additional loads on the shaft were set at specific positions: 5, 15, 20, and 25 cm from the first bearing.

IV. RESULT AND DISCUSSION

The performance analysis of the accelerometer sensor with different rotation and distances of the mass at rotating shaft from three-axis which are x -, y - and z -axis are represented in rotation for 860 rpm and distance of 20 cm as shown in Table 1.

The acceleration of a shaft due to an attached mass depends directly on the distance of the mass from the shaft center. The farther the load is placed, the greater the acceleration amplitude observed over time, while the oscillation frequency is governed by the shaft's rotational speed. The great acceleration amplitude that is obtained in 25 cm distance from first bearing was obtained that shows the farther the load is from the bearing, the greater the force the bearing must withstand to support it, which can increase stress and the potential for greater, not less, vibration. Less vibration occurs because of shorter spans and robust bearings and a well-designed system to absorb vibration energy (see Fig. 1).

TABLE I. RAW DATA OF THE ACTUAL ACCELERATION TIME HISTORY AT 860 RPM AT A LOAD DISTANCE OF 20 CM

Time (s)	x_1	y_1	z_1	x_2	y_2	z_2
1	1.08	1.09	1.07	1.07	1.07	1.06
2	1.09	1.09	1.08	1.08	1.07	1.07
3	1.09	1.09	1.09	1.08	1.08	1.07
4	1.09	1.09	1.08	1.07	1.07	1.06
⋮	⋮	⋮	⋮	⋮	⋮	⋮
500	1.08	1.08	1.06	1.06	1.05	1.05

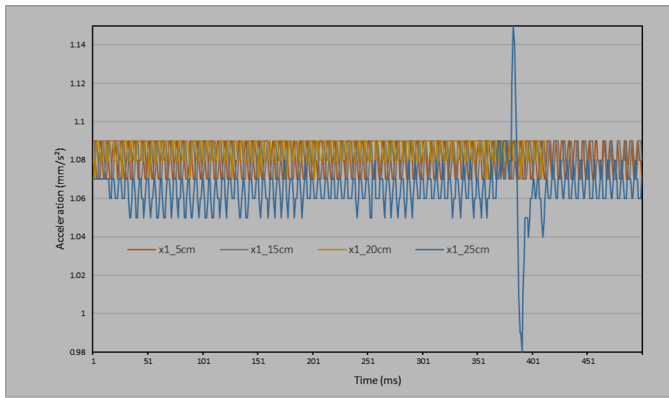


Fig. 1. Acceleration over time at 300 rpm in various load distances on position x1.

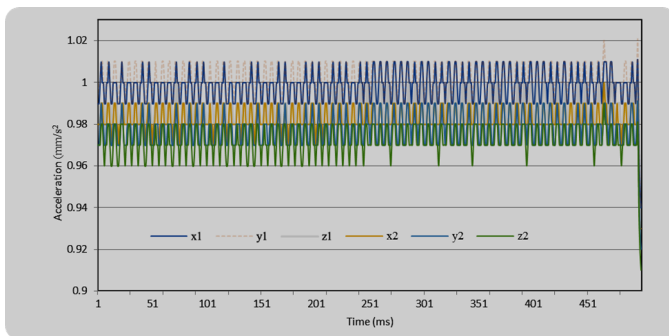


Fig. 2. Vibration acceleration versus time according to shaft rotation of 860 rpm at a load distance of 25 cm

System absorbs energy from the external force and starts vibrating with a larger amplitude. In this step resonance occurs that is leading to excessive vibrations. Engine vibration resonance in this experiment occurs when the time reached 357 ms. In this phase the vibration frequency produced by the engine matches the natural frequency of an engine component or vehicle structure, causing the vibration amplitude to increase significantly. This condition can cause excessive vibration, discomfort to the occupant, and damage to components due to strong vibrations. It can also affect engine performance and vehicle stability. Resonance in this phase occurs when the frequency of the machine's forced vibrations equals the natural frequency of the components or structures connected to it.

Amplitude increases as resonance is reached, with the vibration energy increasing continuously, causing the vibration amplitude to become very large.

These results were confirmed by Wenbin et al., [11] who observed vibration transmission characteristics and measuring points analysis of bearing housing system based on the comparisons between the vibration signals obtained from the defect point and the measuring points on the bearing surface, the transmission mechanism of the defect excitation and the generation mechanism of the bearing housing structural vibration.

The vibration acceleration values on the first sensor on the three axes x_1 , y_1 and z_1 tend to be higher than the values indicated by the second sensor. This indicates the proximity of the power transmission position on the first sensor. It aligns

with those obtained by Hitoshi et al., [12], who observed vibration accelerations near the main bearing.

Testing revealed the highest vibration acceleration at the y_1 axis (Fig. 2). This is because, first, this position is closer to the transmission center. Second, the vibration source at the y -axis pushes or pulls the object in an axial direction along the axis of rotation of the shaft. As a result, the vibration value on the y_1 axis, which is in the same direction as the movement, is greater.

The signal that varies with time, it is realized that time-domain information alone is not enough. A signal plotted against time may show oscillations, but it does not reveal which frequencies are hidden inside that motion. This is where frequency analysis becomes essential, and one of useful tools for such analysis is the PSD (Fig. 3).

For evaluating health of rotating shaft machine, the RMS value is analyzed. It represents the effective energy content of the vibration waveform, providing a measure of its overall intensity. The RMS value smooths out these variations and highlights the average vibrational energy over a given time interval.

The plotted PSD over frequency on allows to observe the vibrational energy of a machine changes as it operates under varying conditions, such as load, speed, or environmental influences. In this rotating machinery, a gradual increase in RMS vibration over time may indicate the development of imbalance, misalignment, or bearing wear. Conversely, a stable RMS trend often suggests consistent performance and mechanical stability.

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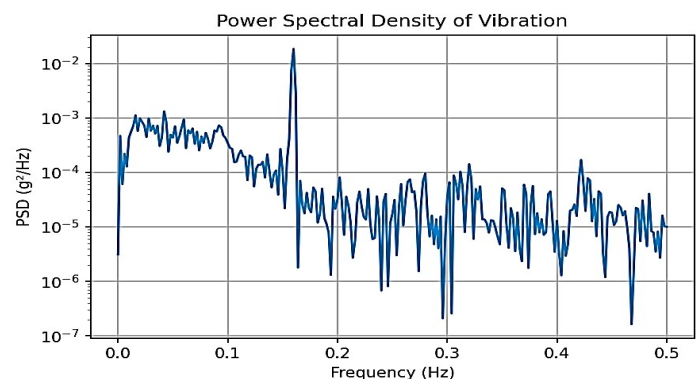


Fig. 3. PSD image for 300 rpm at y_1 position on 25 cm load distance.

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V. CONCLUSIONS

The analysis of acceleration by time history at different axis positions of vibration demonstrates that vibration response is highly dependent on spatial orientation and measurement location. Each axis exhibits distinct dynamic behavior, where variations in amplitude, frequency content, and waveform shape reflect the directional sensitivity of the system.

The analysis of vibration using PSD, frequency spectrum, amplitude, and RMS provide a comprehensive understanding of the system's dynamic behavior. The PSD reveals how vibration energy is distributed across different frequencies, allowing the identification of dominant excitation sources and resonance conditions. The amplitude spectrum highlights the magnitude of vibration response at each frequency, which is essential for detecting critical harmonics and structural weaknesses. Meanwhile, the RMS value serves as a reliable indicator of the overall vibration severity and energy content in the system by combining these parameters, it is possible to evaluate the stability, detect potential faults, and assess the health of rotating machinery or structural components.

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