

MATLAB-Based Vibration Signal Processing for Fault Diagnosis

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Abstract— Traditionally, vibration signal processing has been performed using analog and digital signal analyzers or writing code in intermediate and high-level computer languages. However, the advent of higher-level interpretive-based signal processing software products such as MATLAB has added a new dimension to vibration signal processing. This paper presents a method for analyzing motor vibration data using MATLAB. The method first pre-processes the vibration data to remove noise and baseline wander. Then, the frequency spectrum of the vibration signal is calculated using the Fourier transform. The frequency spectrum is then used to identify the dominant frequencies in the vibration signal. These dominant frequencies can be used to identify potential problems with the motor, such as bearing defects or misalignment. The method was studied on a set of vibration data collected from open source online data of a real motor. The results showed that the method was able to identify the dominant frequencies in the vibration signal accurately. The method was also able to identify the potential problems with the motor. This paper demonstrates the effectiveness of using MATLAB for analyzing motor vibration data. The method presented in this paper can be used to improve the reliability and efficiency of motor maintenance.

Keywords: *Vibration Signal Processing, FFT, Dominant Frequencies, PSD, and CSD,*

1. INTRODUCTION

Rotating machinery signal analysis is the process of extracting information about the condition of rotating machinery from vibration signals. This information can be used to identify and diagnose faults, such as bearing defects, gear tooth wear, and misalignment [1]. MATLAB is a powerful software package that can be used for rotating machinery signal analysis. MATLAB provides a wide range of signal processing functions, including Fourier transforms, time-frequency analysis, and statistical analysis. MATLAB also provides powerful visualization tools that can be used to display and interpret vibration signals. The following are some of the steps involved in rotating machinery signal analysis using MATLAB [2][3]:

The first step is to collect vibration data from the rotating machinery. Collecting vibration data is an important part of the maintenance and monitoring of rotating machinery. Vibration data is a valuable source of information about the condition of rotating machinery.

There are a few different ways to collect vibration data. Accelerometers are the most common type of sensor used to collect vibration data. They measure the acceleration of the machinery, which can be used to calculate the vibration velocity and displacement. Vibration probes are used to measure vibration at specific points on the machinery. They are typically used in conjunction with accelerometers to provide more detailed information about the vibration at different locations. Laser vibrometers are non-contact sensors that can be used to measure vibration at very high speeds [4]. They are often used to measure vibration in rotating machinery, where it is difficult to attach accelerometers.

The following are some of the factors to consider when collecting vibration data. The type of machinery will

determine the type of sensor that is needed. For example, accelerometers are typically used to collect vibration data from rotating machinery, while vibration probes are typically used to collect vibration data from bearings. The sensors should be placed at locations where they can accurately measure the vibration. For example, accelerometers should be placed on the bearings and other critical components of the machinery. The sampling rate is the number of times per second that the vibration data is collected. The sampling rate should be high enough to capture the highest frequency of vibration that is present. The duration of the measurement should be long enough to capture a representative sample of the vibration.

Once the vibration data has been collected, it can be analyzed using a variety of software tools. These tools can be used to identify and diagnose faults, monitor the condition of the machinery, and optimize its performance.

The vibration data may need to be pre-processed before it can be analyzed. This may involve filtering out noise, removing baseline offsets, and normalizing the data. Perform signal analysis. The next step is to perform signal analysis on the pre-processed data. This may involve using Fourier transforms, time-frequency analysis, or statistical analysis to extract features from the data.

A transformation technique should be applied that converts the vibration signal to a different domain, such as the frequency domain or the time-frequency domain, which make the analysis easy and efficient.

2. USES OF MATLAB FOR VIBRATION DATA ANALYSIS

2.1 Interpret The Results

The final step is to interpret the results of the signal analysis. This may involve identifying and diagnosing faults or monitoring the condition of the rotating machinery. MATLAB is a versatile and powerful tool that can be used for a wide range of rotating machinery signal analysis tasks. Its flexibility and interactivity make it a valuable tool for engineers and technicians who need to quickly and easily analyze vibration signals. Here are some specific examples of how MATLAB can be used for rotating machinery signal analysis [5]:

2.2 Fault Detection

MATLAB can be used to identify and diagnose faults in rotating machinery by analyzing vibration signals. For example, MATLAB can be used to identify bearing defects by looking for changes in the frequency spectrum of the vibration signal. MATLAB can be used to monitor the condition of rotating machinery by tracking changes in vibration signals over time. This can be used to identify potential problems before they cause a failure.

2.3 Machine Optimization

MATLAB can be used to optimize the performance of rotating machinery by analyzing vibration signals. For example, MATLAB can be used to identify ways to reduce vibration levels or improve the efficiency of the machine. MATLAB is a valuable tool for engineers and technicians who need to analyze vibration signals from rotating machinery. Its flexibility, interactivity, and range of features make it a powerful tool for a variety of tasks, from fault detection to condition monitoring to machine optimization.

3. MATHEMATICAL MODELING

Mechanical vibration analysis often entails the use of intricate mathematical and statistical formulas. Fortunately, MATLAB tools greatly simplify the handling of such complexities. Assuming an electric motor is mounted on a spring-supported system, which includes a damper to reduce vibrations on the foundation, the following equations can be employed for the system's vibration analysis [6][7].

Equation of motion:

$$F(t) = m\ddot{x} + c\dot{x} + kx \quad (1)$$

Where, $F(t)$ is the external force acting on the system m is the mass of the system, c is the damping coefficient of the system, k is the spring constant of the system and x is the displacement.

The natural frequency of vibration:

$$\omega_n = \sqrt{k/m} \quad (2)$$

where, ω_n is the natural frequency of vibration in rad/s.

Damping ratio:

$$\zeta = c/2\sqrt{km} \quad (3)$$

where, ζ is the damping ratio.

Forced vibration response:

$$x(t) = A \sin(\omega t + \theta) \quad (4)$$

where, $x(t)$ is the displacement of the system at time t , A is the amplitude of vibration, ω is the frequency of the forcing function, and θ is the phase angle between the displacement and the forcing function.

3.1 Time-Domain Analysis

Step response:

$$x(t) = x_0(1 - e^{-t/\tau}) \quad (5)$$

where, x_0 is the initial displacement of the system at $t = 0$, and τ is the time constant of the system.

Impulse response:

$$h(t) = H \delta(t) \quad (6)$$

where, $h(t)$ is the impulse response of the system, H is the system gain, and $\delta(t)$ is the Dirac delta function.

Fourier transform:

$$X(\omega) = \int_{-\infty}^{\infty} x(t) e^{-j\omega t} dt \quad (7)$$

where, $X(\omega)$ is the Fourier transform of $x(t)$, and ω is the frequency variable.

3.2 Frequency-domain analysis

Frequency response:

$$H(\omega) = X(\omega)/X_0(\omega) \quad (8)$$

where, $H(\omega)$ is the frequency response of the system, $X(\omega)$ is the Fourier transform of $x(t)$ and $X_0(\omega)$ is the Fourier transform of $x_0(t)$.

Power spectral density (PSD):

$$S_x x(\omega) = |X(\omega)|^2 \quad (9)$$

where, $S_x x(\omega)$ is the PSD of $x(t)$, $|X(\omega)|$ is the magnitude of the Fourier transform of $x(t)$.

Cross-spectral density (CSD):

$$S_x y(\omega) = X(\omega) X^*(\omega) \quad (10)$$

where, $S_x y(\omega)$ is the CSD of $x(t)$ and $y(t)$, $X(\omega)$ is the Fourier transform of $x(t)$, and $X^*(\omega)$ is the complex conjugate of the Fourier transform of $x(t)$.

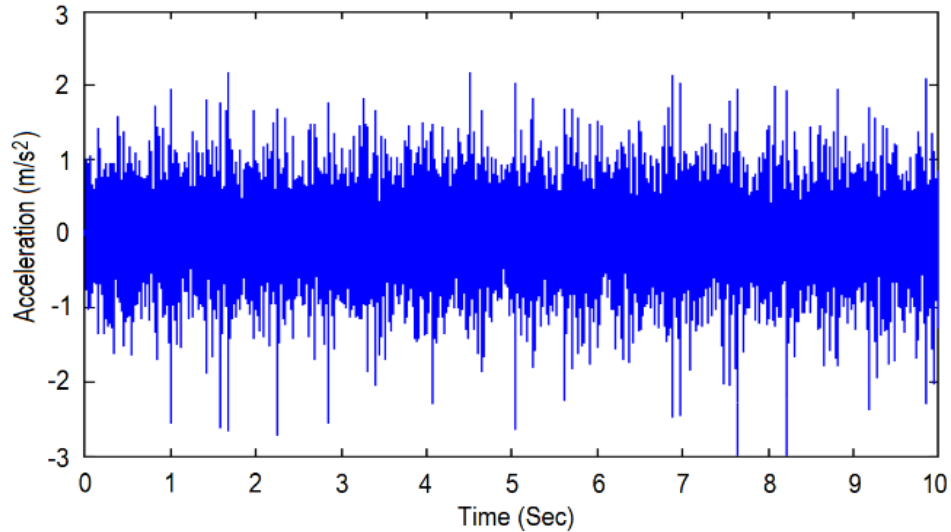
Wiener spectrum:

$$S_x x(\omega) = S_x x^*(\omega) |H(\omega)|^2 \quad (11)$$

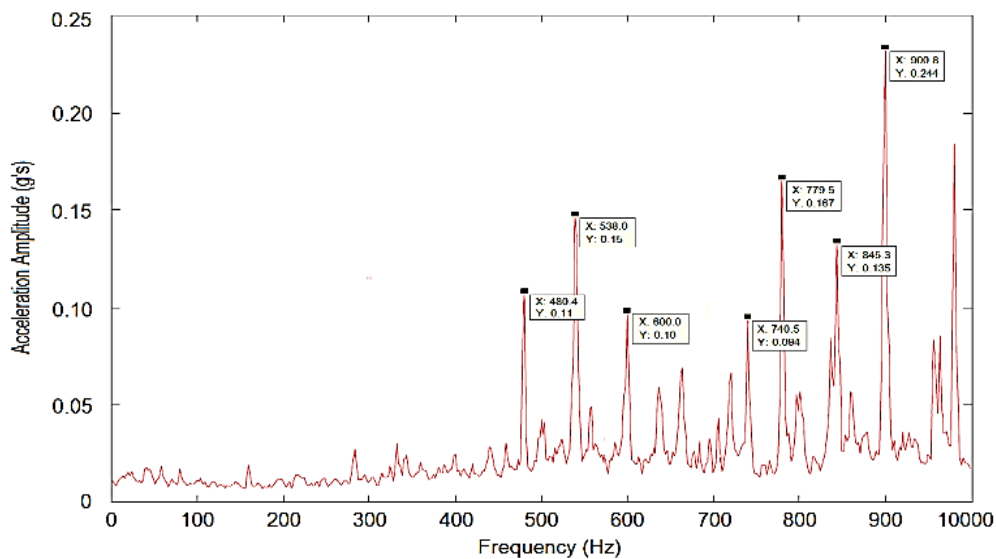
where, $S_x x^*(\omega)$ is the power spectral density of the excitation, $|H(\omega)|$ is the magnitude of the frequency response.

4. RESULT AND DISCUSSION

The graphical representation of the time-domain and frequency-domain signals from a normally balanced rotating electric motor is displayed in Fig. 1(a) and (b), respectively. This graphical analysis was generated using MATLAB software. The data was captured from the sensor over a 10 ms time frame with a sampling rate of 20 kHz. In Fig. 1(b), although the motor was in a balanced condition, there are some spikes at the natural frequency and their harmonics, which is considered normal.



(a)



(b)

Fig. 1 Normal vibration signal of an electric motor, (a) time-domain and (b) frequency-domain

In contrast, the graphical representation of the time-domain and frequency-domain signals from the rotating electric motor in an imbalanced condition is shown in Fig. 2(a) and (b), respectively. It can be challenging to discern differences between the time-domain signals in Fig. 1(a) and Fig. 2(a) as they appear quite similar. However, the frequency-domain signals in Fig. 2(b) reveal new frequency spikes, and there is a higher frequency power distribution in the 700 Hz to 800 Hz frequency band compared to the frequency-domain signals in Fig. 1(b). These findings clearly indicate an abnormality or imbalance condition in the motor in the case of 2 (Fig. 2).

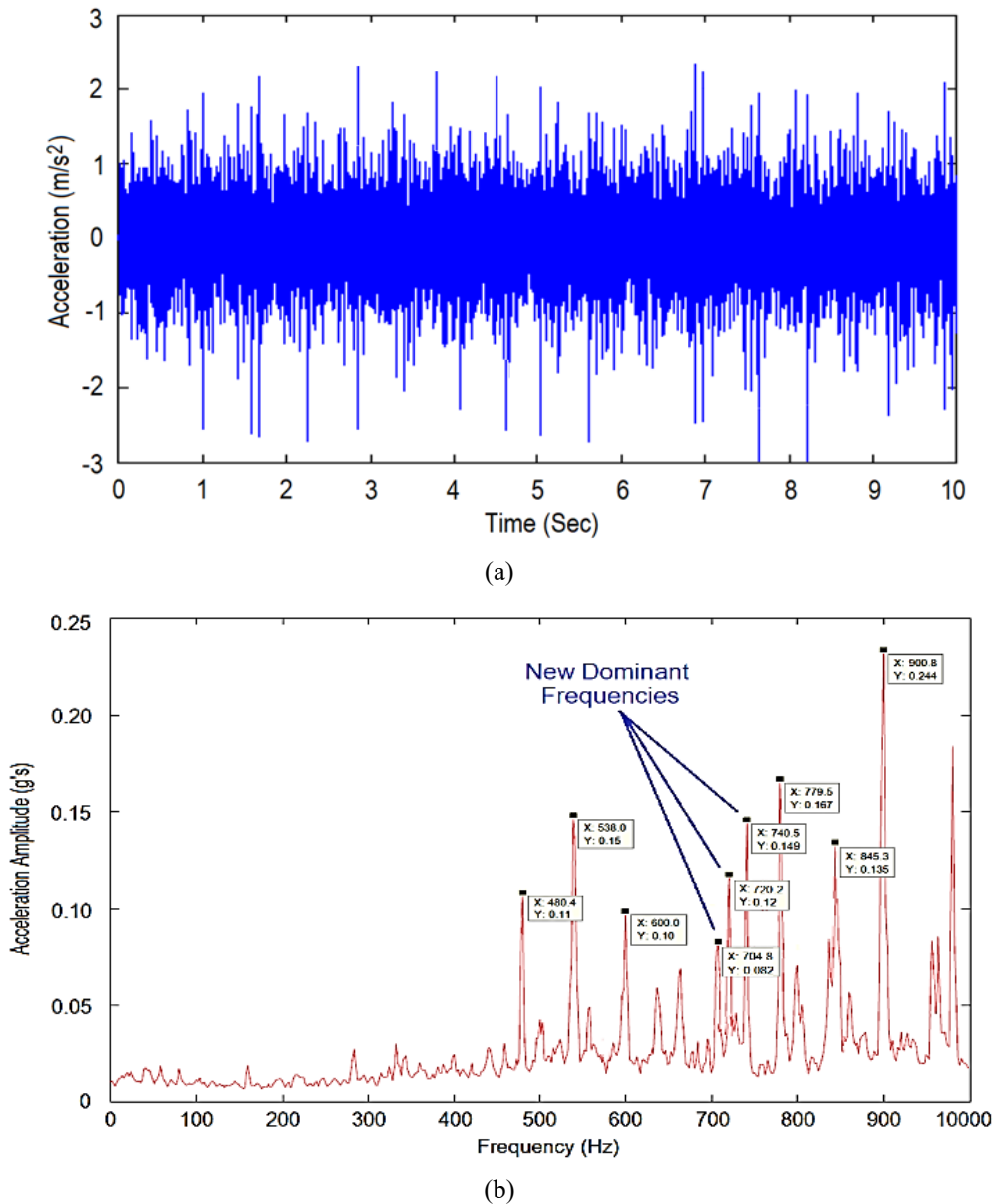


Fig. 2 Vibration signal of an imbalanced electric motor, (a) time-domain and (b) frequency-domain

5. CONCLUSION

Analyzing vibration data for electric motor balancing and health condition analysis can be a complex task. Nevertheless, MATLAB software tools can significantly simplify this analysis process. In this research, online real-time data from electric motors is employed to assess their condition. It's important to note that the accuracy of vibration data values depends on the sensor's placement [1]. However, the frequency spectrum trends in the data remain consistent for both healthy and faulty motors.

REFERENCES

- [1] W. Zhu, H. Lin, W. Sun and J. Wei, "Vibration Performance of Traction Gearbox of a High-Speed Train: Theoretical Analysis and Experiments," *Actuators*, vol. 12(103), pp. 1-34, 2023.
- [2] M. B. Joshi and K. S. Pujari, "Fault Diagnosis of High-Speed Rotating Machines Using MATLAB," *Diagnostyka*, vol. 24(2), pp. 1-8, 2023.



- [3] S. Cho, K. Jeon and C. W. Kim, "Vibration Analysis of Electric Motors Considering Rotating Rotor Structure Using Flexible Multibody Dynamics-Electromagnetic-Structural Vibration Coupled Analysis," *Journal of Computational Design and Engineering*, vol. 10, pp. 578–588, 2023.
- [4] Kang, S. G., La, J. P., Yoon, H. S., Choi, D. Y., & Park, K. H. "New Synthetic Heterodyne Laser Doppler Vibrometer for Measurement of Mechanical Vibrations with Submicron Amplitude," *Key Engineering Materials*, vol. 381–382, pp. 43–46, 2008.
- [5] I. Howard, "Vibration Signal Processing Using MATLAB," *Acoustics Australia*, vol. 23(1), pp. 9-13, 1995.
- [6] V. K. Ingle, and J. G. Proakis, *Digital Signal Processing Using MATLAB*, 3rd Ed. 3, Cengage Learning, 2011.
- [7] S. Graham Kelly, *Advanced Vibration Analysis*, CRC Press, Taylor & Francis Group, New York, 2006.