# System Condition Monitoring and Health Assessment Using Statistical and Signal Processing Approaches

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## 1. Abstract

Predictive Maintenance has become a major issue in industrial system health monitoring as the machines are operating under more complex and diverse conditions nowadays. Starting from the early preventive maintenance methods, health monitoring and prognosis of engineering systems have been an extensive concern for engineers to lower the maintenance cost and higher system protection. Besides conserving from catastrophic failure, a proper maintenance scheme can amplify system yield as well as reduce production and maintenance costs. Once, maintenance was considered as a cost center of industries but, nowadays it is regarded as a profit center [1]. Researchers have developed different methods for assessing the state of health (SOH) for different systems. Such as- Vibration Analysis for Gearboxes [2], Bearings [3], Motors [3]; Current Signature Analysis for Induction Motors, DC Motors etc. [4]. Among them, vibration analysis for rotary machineries has been quite popular among the researchers and it is adopted by many industries too for the evaluation of SOH.

In this paper, vibration response of Brushless DC (BLDC) Motor is presented for different operating conditions. BLDC motor is a widely used component in various industrial applications for its higher efficiency, better torque-current ratio etc. Proper condition monitoring of BLDC motor can increase the efficiency and reduce the life-cycle cost of various industrial systems such as aerospace, defense, manufacturing etc.

A conventional Generator-Motor set (G-M set) is used to collect the vibration samples from motor. A generator is coupled with the motor and different loading were applied to the generator end. Figure 1 illustrates the test-rig setup for BLDC motor test.

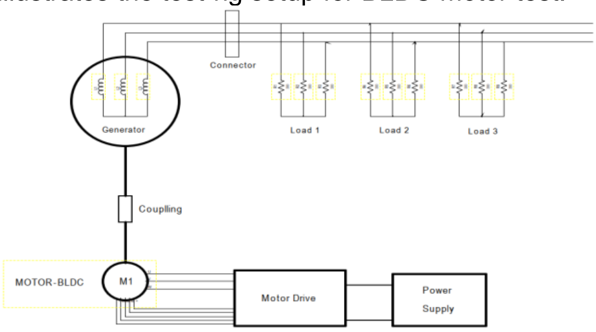


Fig. 1: Illustration of G-M set

Spectral analysis of vibration signals for fault diagnosis has been a promising approach this far [1]. It allows us to determine the anomaly in vibration signals through visual analysis. In this paper, vibration samples are analyzed in time domain, frequency domain and time-frequency domain using several approaches such as- Fourier Transform, Wavelet Analysis, Wigner-Vile distributions etc. Later, using several statistical methods the trend of motor health degradation is predicted. Later, extracted features from different domains that indicate the SOH of a system were classified and predicted using several statistical approaches.

Discrete Fourier Transform (DFT) for a time domain signal *x(n)* can be expressed as Eq (1):

$$X_k = \sum_{n=0}^{N-1} x(n)\, e^{-\frac{i2\pi nk}{N}} \tag{1}$$

Where:

- $X_k$ = Transform Values
- *x(n)* = Motor Vibration Samples
- *N* = Number of Samples
- *k* = Each k^th value is a complex number including amplitude and phase shift.

Equation (2) shows the Continuous Wavelet Transform (CWT) for vibration signal $x(n)$ as:

$$X_{\omega(a,b)} = \frac{1}{|a|^{\frac{1}{2}}} \int_{-\infty}^{\infty} x(n)\varphi\left(\frac{t-b}{a}\right) dt \tag{2}$$

Where:

- $\varphi$ = Mother Wavelet
- *a* = Scaling Factor
- *b* = Translation Factor

Figure 2(a) represents the time domain samples of motor vibration in healthy case and faulty case. Figure 2(b) and 2(c) illustrates the signals in frequency domain and time-frequency domain, respectively. Analyzing these figures, we can have an intuition on the fault frequencies and sidebands of faulty motor vibration signal.

Figure 3(a) and 3(b) shows the normal distribution of motor vibration samples. Faulty vibration samples are more widespread compared to the healthy ones in the sample space.

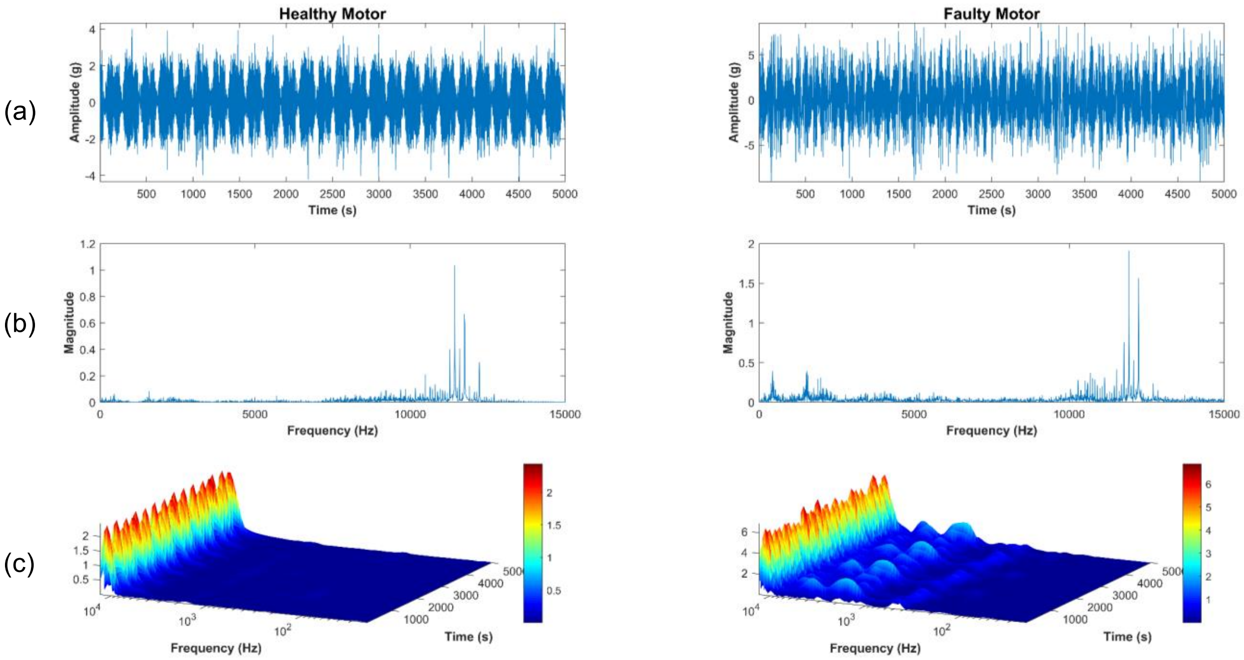


Fig. 2: Motor Vibration Samples in (a) Time, (b) Frequency and (c) Time-Frequency Domain

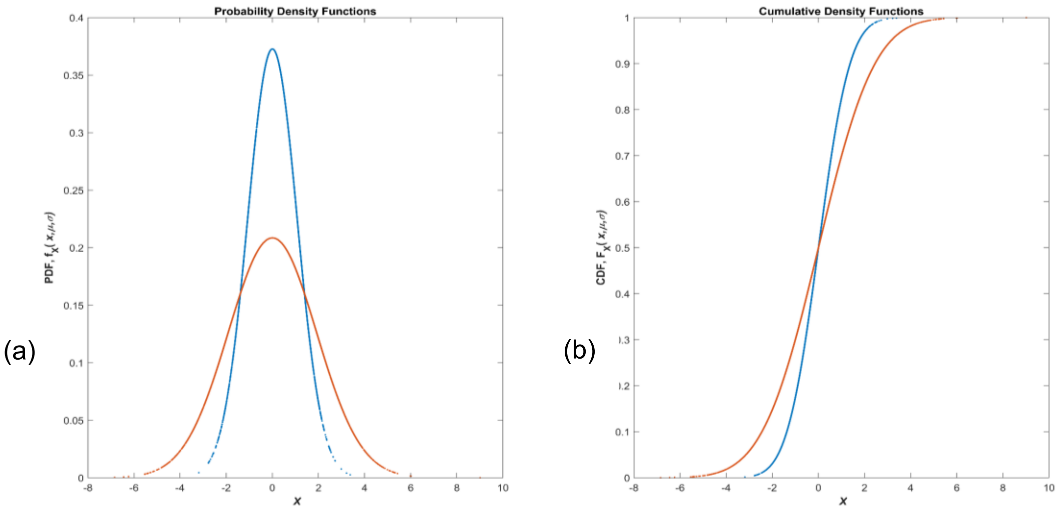


Fig. 3: Motor Vibration Samples in Normal Distributions (a) PDF, (b) CDF

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