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## **Optimization & Fault discovery of Induction Motor by Current Signature Analysis technique**

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### **ABSTRACT**

Induction Motor (IM) faults, such as air gap eccentricity, rotor faults, short-circuits, and bearing faults, can be detected through conditional monitoring, which requires expensive tools. Digital Signal Processing (DSP) offers a cost-effective solution by using IM Current Signature Analysis (IMCSA) to identify faults. Faulty motors exhibit different frequency spectra in their line current compared to healthy ones due to harmonic components. IMCSA detects and analyzes these changes using Lab VIEW software for direct online monitoring. This paper discusses the impact of motor faults, fault tracking, and the use of Fast Fourier Transforms (FFT) for frequency spectrum analysis from analog current data, outlining the transformation process and experimental procedures for fault detection.

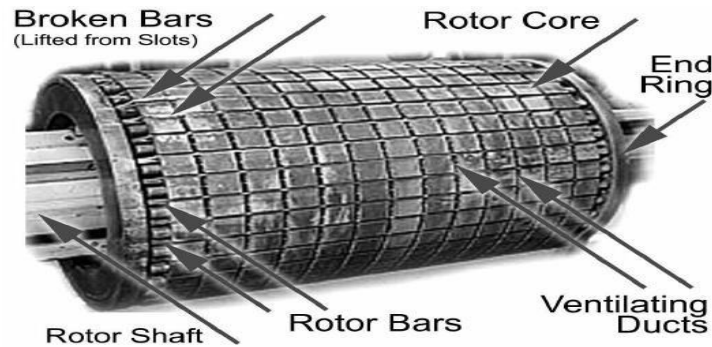
**Keywords:** Digital Signal Process, Fast Fourier Transforms, Current Signature Investigation, Fault Detection

### **1 Introduction**

Induction motors, also known as asynchronous motors, are widely used in industrial and engineering applications due to their robustness, despite generally low performance. These motors often face harsh conditions, leading to overloading, inadequate cooling, excess noise, and vibrations, which can cause bearing faults, broken rotors, winding faults, rotor eccentricity, and brush issues. Continuous monitoring, such as thermal, noise, vibration, and torque monitoring, is needed but requires expensive tools and skilled labor [1]. Advances in Digital Signal Processing (DSP) provide a cost-effective solution for fault detection using software tools, saving both time and expense. IM Current Signature Analysis examines the frequency spectrum of a motor's stator current, identifying variations between healthy and faulty motors to locate different faults [1].



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**Figure 1:** Induction motor with broken rotor

## 2 General Faults

### 2.1 Broken rotor fault

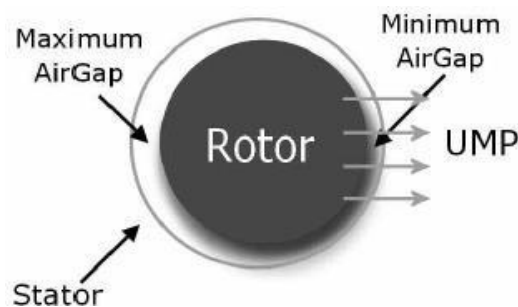
Broken rotor bars strike the stator core and windings at high speeds, causing mechanical damage or insulation failure, leading to winding damage. This occurs due to brazing problems, thermal stress, or end-ring pressure.

### 2.2 Air gap eccentricity

Misalignment of the rotor or stator during manufacturing causes unbalanced magnetic pull (UMP), damaging the core and windings, and increasing motor vibrations and noise. There are three types of eccentricity (i.e. Static eccentricity, Dynamic eccentricity and mixed eccentricity).

### 2.3 Rotor faults

Insulation failure in the armature is mainly due to abrupt temperature rises, wedge damage, loose bracing, or contamination by oil, moisture, and dirt, potentially leading to short circuits.



**Figure 2:** Illustration of UMP

Machine faults cause unbalanced voltage and current, altering torque and increasing motor losses, which decreases efficiency and raises heat and noise levels. Monitoring these faults is

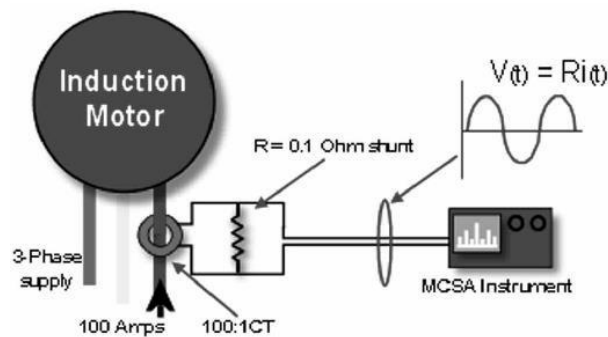


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crucial. While equipment costs are high, online monitoring provides an easier and cost-effective solution for fault detection [2].

### 3 Induction Motor Current Signature Analysis (IMCSA)

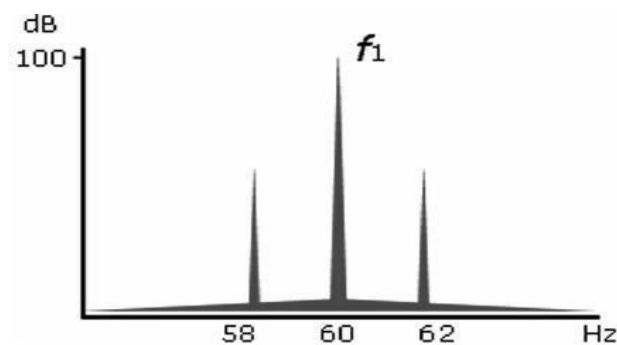
IMCSA detects faults in a three-phase induction motor during operation by analyzing current online [2]. A basic IMCSA system includes a current transformer (CT) to sense the signal, shunt resistance across the CT output and IMCSA instrument (spectrum analyzer) to produce the current signature [2].



**Figure 3:** Basic IMCSA instrumentation system

#### 3.1 Principle of Operation

In an induction motor, the fundamental frequency ( $f$ ) is accompanied by harmonic frequencies ( $mf$ ), where  $m$  is the harmonic number. These harmonics slightly alter the amplitude and induce flux that interacts with the rotor. This generates rotor current, producing flux that links with the air gap at the harmonic frequency. A rotor fault changes the amplitude of the stator current at this frequency. By comparing the Stator current amplitude of a healthy and faulty motor, faults can be detected [2]. Different faults produce harmonics at different frequencies, known as side band frequencies.



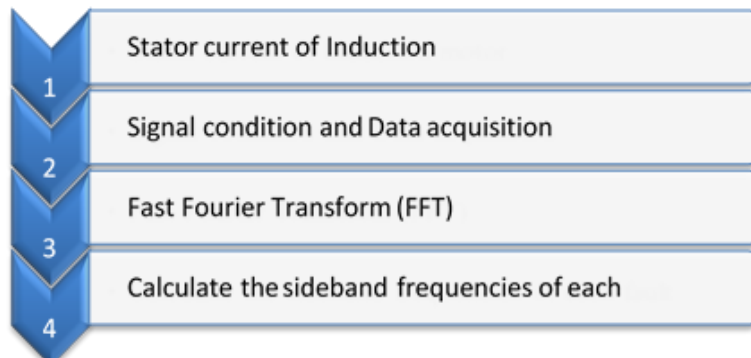
**Figure 4:** Illustration of current signal in frequency domain showing the fundamental frequency  $f_1$  and two sidebands



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Stator current contains unique frequencies for different faults, which can be analyzed by transforming the time-domain current into the frequency domain using Digital Signal Processing (DSP) techniques like Fast Fourier Transforms (FFT) and Wavelet analysis.

- **Stepwise Procedure:** The analog stator current is converted into a discrete-time signal (DTS) for fault detection using a data acquisition card (DAC).



**Block 1: Steps in IMCSA**

The DAC, which includes digital-to-analog and analog-to-digital converters, interfaces between the computer and the motor. The acquired signal is then transformed into the frequency domain using FFT, facilitated by software like MATLAB or Lab VIEW [2]. The critical process of calculating sidebands for each fault will be explained in the following sections.

### 3.2 Broken Rotor Analysis of IM

A decibel (dB) versus frequency spectrum is typically used to detect unique current signature patterns of different faults. The rotating magnetic field (RMF) induces rotor voltage and current at slip frequency, producing a 3-phase RMF at slip frequency relative to the rotor [3]. In case of a rotor fault, a backward RMF is generated at slip frequency, altering the current spectrum by inducing voltage in the stator. The forward RMF in the IM rotates with synchronous speed ( $N_1$ ).

$$N_1 = \frac{120f_1}{P}$$

Here,  $f_1$  is supply frequency and  $p$  is the poles. Now slip ( $s$ ) will be,

$$s = \frac{N_1 - N}{N_1}$$

Here,  $N$  is the rotor speed and Slip speed ( $N_2$ ) will be,

$$N_2 = N_1 - N \text{ \& } s = \frac{N_2}{N} \text{ \& } N_2 = s \cdot N_1 \text{ \& } N = (1 - s)N_1$$



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The backward rotating magnetic field generated by the rotor, due to a broken bar and in relation to the rotor is;

$$\text{Backward RMF speed } N_b = N - N_2 = [(1 - s) N_1] - s \cdot N_1 = (1 - 2s) N_1$$

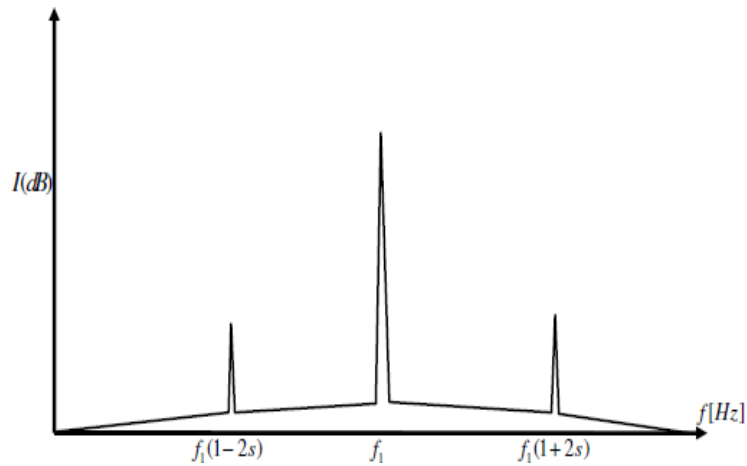
Due to slip frequency, two sidebands occur, each equal to;

$$f_b = (1 \pm 2s) f_1$$

The occurrence of multiple broken rotor bars results in the formation of a sequence as,

$$f_b = (1 \pm 2ks) f_1$$

Where  $K = 1, 2, 3$  etc.

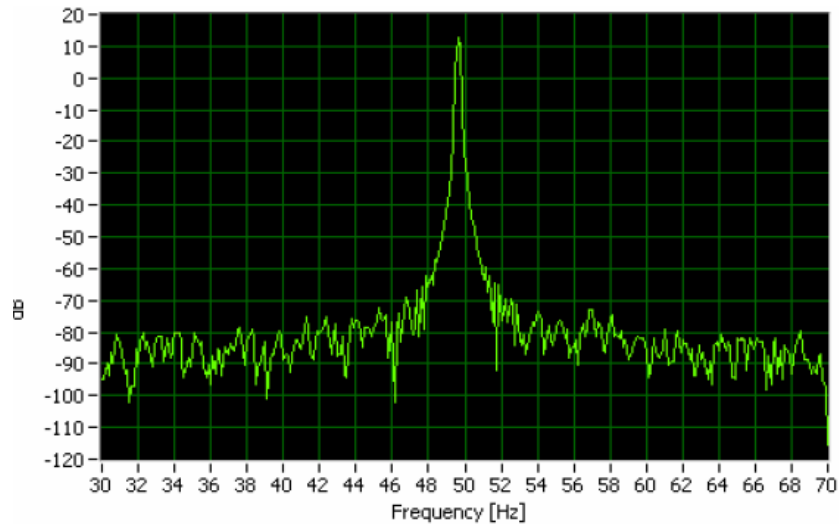


**Figure 5:** Frequency spectrum of broken rotor bars

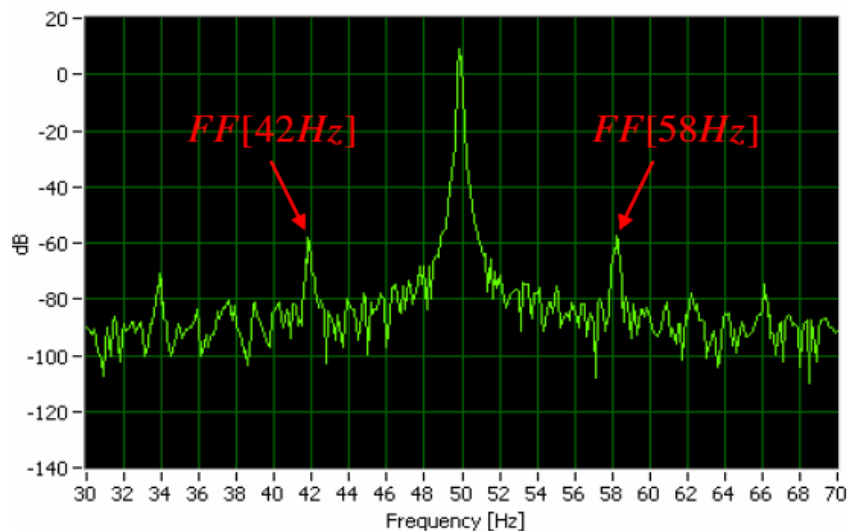
As a result of a broken rotor bar, two sidebands corresponding to the slip frequencies appear [4] [5]. When the amplitude of these sidebands surpasses a certain threshold, typically set at 40dB, it indicates a broken rotor bar. The experimental observations, as depicted in Fig. 6, demonstrate this phenomenon.



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**Figure 6a:** Power spectrum of healthy motor



**Figure 6b:** Power spectrum of motor with broken bar under full load

### 3.3 Air Gap Eccentricity

The sideband frequencies resulting from air gap eccentricity are determined using magnetomotive force (MMF) [6]. These frequencies are identified as;

$$f_{ecc} = f_1(R \pm n_d) \left\{ \frac{1 - 2s}{p} \right\} \pm n_{ws}$$

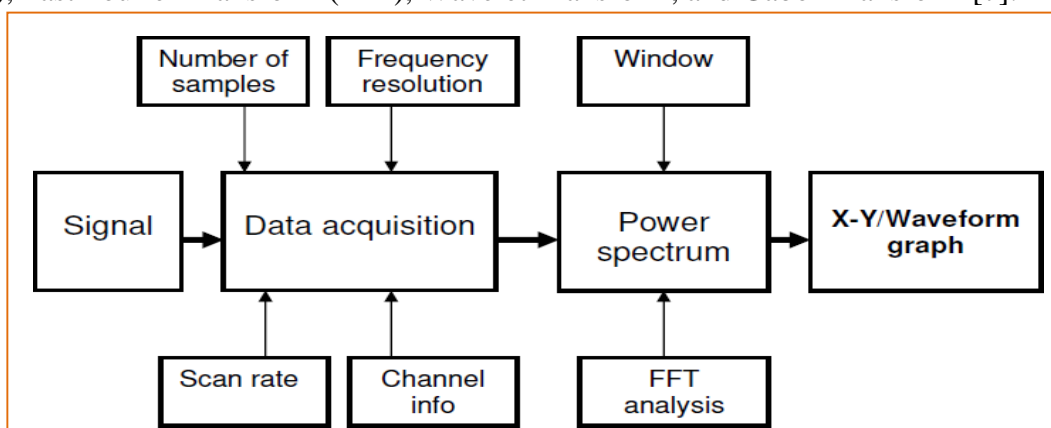
Here,  $f_{ecc}$  = frequency component of air gap eccentricity,  $R$  = Number of Rotor slots,  $P$  = pole pairs and  $n_d = 0$  for static eccentricity; 1, 2, 3, etc. for dynamic eccentricity;  $n_{ws} = 1, 3, 5$  etc.



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### 3.4 Signal Processing Technique

Signal processing techniques are used to convert the current signal into useful information for diagnosing faults. Some of the transformation methods are Short Time Fourier Transform (STFT), Fast Fourier Transform (FFT), Wavelet Transform, and Gabor Transform [7].



**Figure 7:** Obtaining power spectrum Blocks

For analysis, FFT is useful and straight forward. Discrete Fourier Transform (DFT) is the most direct mathematical method to determine the frequency components of a time domain sequence [7]. FFT is the simplest and most efficient way to calculate DFT.

## 4 Conclusion

The fault detection of induction motors is examined through the analysis of broken rotor bars, air gap eccentricity, and advanced signal processing techniques. By employing magnetomotive force (MMF) to identify sideband frequencies caused by air gap eccentricity, and utilizing Fast Fourier Transform (FFT) for frequency component determination, the research demonstrates effective methodologies for fault detection. The broken rotor bars analysis, implemented through Lab VIEW software, provide a reliable and efficient approach for diagnosing induction motor faults, ultimately contributing to improved maintenance and operational efficiency in industrial applications.

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