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Detection of Bearing Faults in Induction Motor using Short Time Ramanujan Fourier Transform

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Abstract: Machine condition monitoring of the vibration signals based on Short Time Ramanujan Fourier Transform (ST-RFT) is proposed. The vibration analysis of rotating machine is very useful in machine condition monitoring. The previous method like STFT and Wavelet Transform are very popular approaches for identifying the transient associate with faulty bearing vibration signal. In this paper ST-RFT is used to detect the faults in vibration signal and it gives the better resolution compared to STFT and Wavelet Transform.

Keywords: Vibration signal, Condition monitoring, Time frequency analysis, Ramanujan Fourier Transform.

I. Introduction

The study of condition monitoring of machines and fault diagnosis is a challenging task. The induction motor is widely used in all type of industrial applications, due to their simple construction, high reliability and high efficiency. These machines can be subjected to various types of faults due to temperature, lubricant problem, corrosion etc [1]. Bearing faults in machine appear as transients periodically present in the vibration data. There are many types of faults that can appear in the machine. These faults can be classified like stator fault, rotor fault and bearing fault. The bearing is an essential component of the machine and bearing failure mostly occurs in induction motor. For this reason detection and analysis of such types of irregular vibration signals are necessary. Therefore, condition monitoring and fault diagnosis is most important for ensuring the safe running of machines. Vibration signal analysis is a very important method to use for condition monitoring and faults diagnosis, which is used to find simple and effective method for diagnosis and analysis of vibration signal. The important information and dominant feature of the signal can be extracted for diagnostics. Many signal processing methods have been used for fault diagnostics, among which the Fast Fourier Transform (FFT) and Short Time Fourier Transform (STFT) are widely used and well established methods unfortunately the FFT based methods are not suitable for non stationary signals and not able to enhance information of non stationary signals [2]. Because of this disadvantage of FFT analysis it was necessary to find supplementary method for non stationary signal such as STFT, Continuous Wavelet Transform (CWT) [3], and Wigner-Ville Time Frequency Distribution (WVD). The time frequency analysis is widely used for faults diagnosis [4], such as STFT and CWT [5]. But each of the time frequency method has suffered some problems. It is no doubt that the STFT gives the intuitive interpretation of the results but the time frequency resolution of STFT is constant for the given window size. CWT and Discrete Wavelet Transform (DWT) are used for multi-resolution and conditionally fully reversible. WVD is good for concentration in the time frequency plane but the support areas of the signal do not overlap each other therefore interference terms will appear on the time frequency plane and this will mislead the signal analysis. In order to overcome these disadvantages, many advanced methods such as Choi-Williams Time Frequency Distribution (CWD) and Cone-Shaped Distribution (CSD) are used, but these suffer from cross terms and irreversibility. Propose method describes condition monitoring of vibration signal using Ramanujan Fourier Transform.

The work is divided into five sections in this paper. Section II describes machine condition monitoring. Section III describes Ramanujan Fourier Transform. Condition monitoring using RFT is described in section IV. Work is concluded in section V.

II. Machine Condition Monitoring

In modern manufacturing industry, the role of machinery condition, maintenance activities are very important and essential for those large scale and important equipments and infrastructures as these failures may result insignificant economic loss & data loss.

Therefore the condition based maintenance (CBM), is very important, which supervise maintenance activities on the basis of machinery health condition. The successful implementation of CBM depends on accuracy, efficiency of method and identification of healthy and faulty condition of machinery, which is realized by machine condition monitoring system. Machine condition monitoring means identification and detection of health condition using collection of data or information from machinery. Normally the information used can be vibration signal, acoustic emission and temperature etc. The vibration signals are easy to collect and contain abundant information related to machine condition. The simple flow chart of condition based monitoring (CBM) is shown in figure (1) and it consists of four steps [6].

(a) Data acquisition unit, to collect vibration signal or data related to system health condition.

(b) Data processing unit, to analyze the collected data or vibration signal and extract the most useful information contained in raw data.

(c)Condition description unit, to characterise the health condition of machine based on results in step two.

(d) Maintenance decision-making unit, to suggest maintenance activities and take decision that what to do under certain conditions.

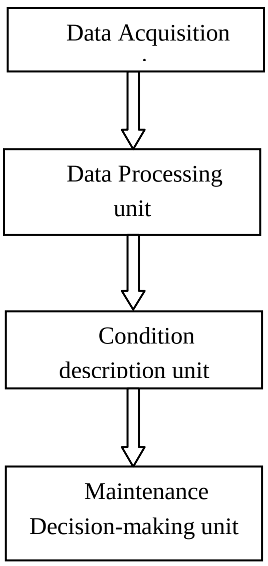

Figure1. Flow chart of CBM program

The vibration signals are acquired from the induction motor (single phase) under the loaded condition. The induction motor was run with healthy and faulty bearing (6203-2Z-H320B-JEM-SKF). The vibration signal was taken by accelerometer (ESPL3X15) and the simulation time has been taken as 1 second [7].

III. Ramanujan Fourier Transform

In the traditional method of frequency spectrum analysis is DFT [8]. The basis function of $x_e(k)$ is define as [9]

$$x_e(k) = \exp\left(2\Pi j \frac{p}{q} k\right), \text{ p=1 …q.} \quad (1)$$

By eq. (1) it is clear that $x_e(k)$ are obtained as multiple of a basic frequency of $\left(\frac{1}{q}\right)$ [10].

In the RFT, Ramanujan sums $c_q(k)$ are sums define as the k-th power of q-th primitive roots of unity [11]

$$c_q(k) = \sum_{p=1;(p,q)=1}^{q} \exp\left(2\Pi j \frac{p}{q} k\right) \quad (2)$$

It is clear that $x_e(k)$ are the primitive characters $c_q(k)$ [12].

That means the basic functions are built by summing up component which are multiple of the periodicity q and the component which satisfying $(p,q)=1$ will contribute the sum and p & q are co prime.

The sums were originated by famous Indian mathematician Ramanujan play important role in typical arithmetical function $x(n)$ may be express as a linear combination [8].

$$x(k) = \sum_{q=1}^{\infty} S(q) c_q(k) \quad (3)$$

Where S(q) is known as the Ramanujan coefficients.

Now consider the $A_v(g)$ as the mean value of function $g(k) = x(k)c_q(k)$ and it is defined as [13]

$$A_v(g) = \lim_{N\to\infty} \frac{1}{N}\sum_{k=1}^{N} g(k) \quad (4)$$

Then the Ramanujan coefficient are given by

$$S(q) = \frac{1}{\phi(q)} A_v\left[x(k)c_q(k)\right] \quad (5)$$

$$S(q) = \frac{1}{\phi(q)} \lim_{N\to\infty} \frac{1}{N}\sum_{k=1}^{N}\left[x(k)c_q(k)\right] \quad (6)$$

Where $\emptyset(q)$ is the Euler totient function, the eq. (6) is a ideal mathematical concept and it has many ways to practical computation, now the finite summation is given by

$$S(q)=\frac{1}{N\phi(q)}\sum_{k=1}^{N}x(k)c_q(k),\ q=1,2.....k \qquad (7)$$

The eq. (7) is a Ramanujan Fourier Transform and N is the length of the signal.

Now consider the sinusoidal signal having three sine components with frequency 20, 40 and 80 Hz as shown in figure (2). Then we applied STFT, WT and STRFT transforms to this test signal. The experimental results shows that ST-RFT is giving the information about the period of the signal with high accuracy and the periods are obtained in the location 12, 24 and 48. The STFT has poor time localization and WT result has poor concentration.

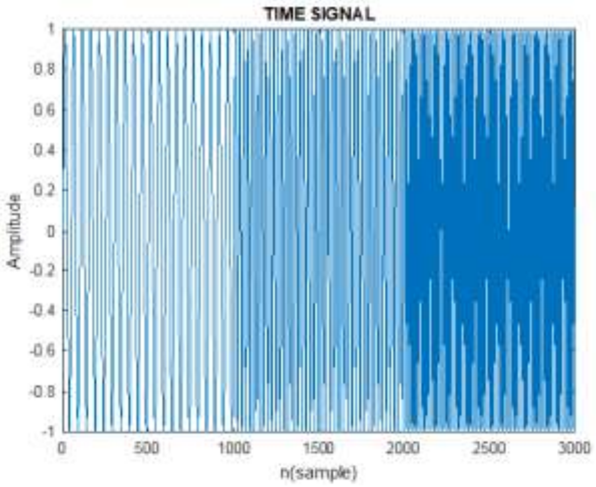

Figure2. Harmonic wave

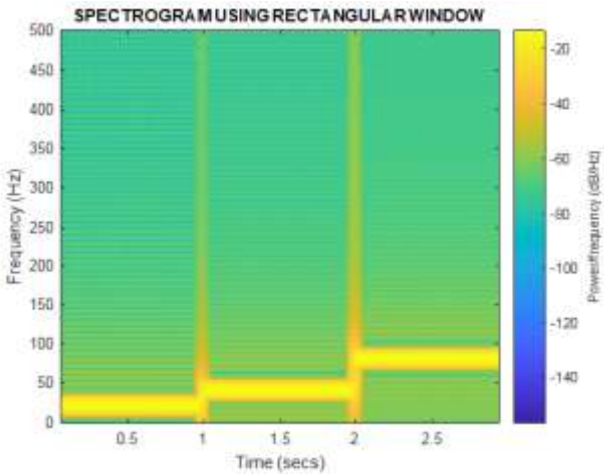

Figure3. STFT spectrogram

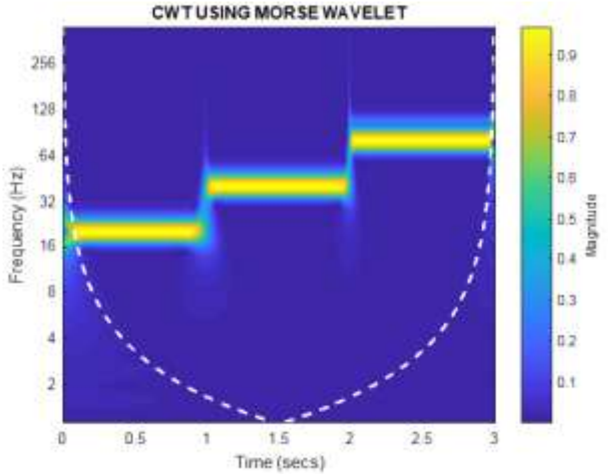

Figure4. Wavelet Transform using Morse Wavelet

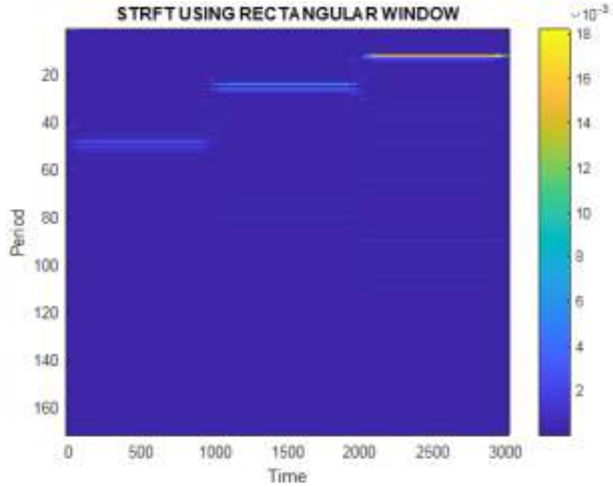

Figure5. ST-RFT using rectangular window

IV. Condition Monitoring using Ramanujan Fourier Transform

The machine condition monitoring of vibration signal based on RFT has been described in this section. First the healthy vibration signal was taken and was analyzed using ST-RFT. The healthy vibration signal is shown in figure (6) and the FFT of the healthy vibration signal gives the information about characteristics frequency which is shown in figure (7) [7]. The spectrogram using rectangular window of length 128 is shown in figure (8). The scalogram using Morse Wavelet is shown in figure (9) and the spectrogram using ST-RFT is shown in figure (10), the ST-RFT of healthy vibration signal shows that there is no transient in any location of the signal. Now consider the faulty vibration signal shown in figure (11). In the faulty vibration signal, we obtained the transient in time domain and these transients were capture by time frequency analysis. The spectrogram is not able to localize the transients in both time as well as frequency domain as shown in figure

(12). The scalogram results suffer poor time resolution as shown in figure (13). The ST-RFT gives the better results compared to STFT and Wavelet Transform as shown in figure (14) with good resolution. The ST-RFT gives the information about the period directly. The other application of Ramanujan Fourier Transform is de-noising of vibration signals.

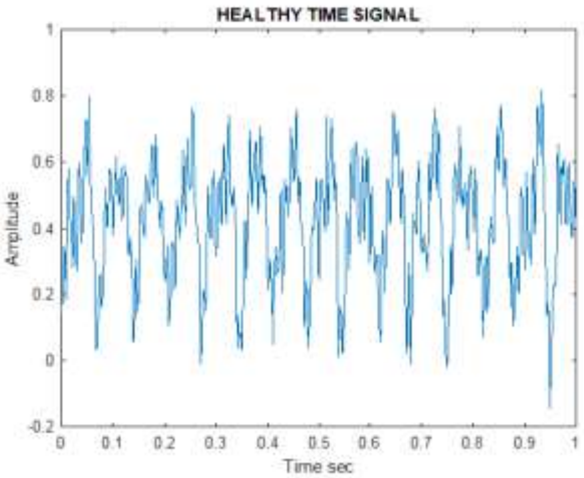

Figure6. Healthy time signal

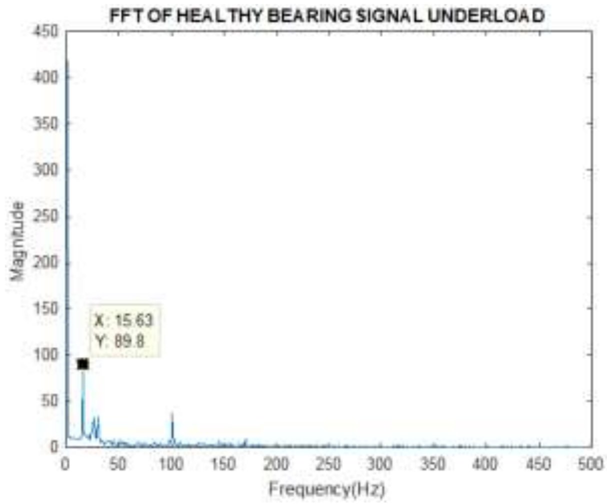

Figure7. FFT of healthy time signal

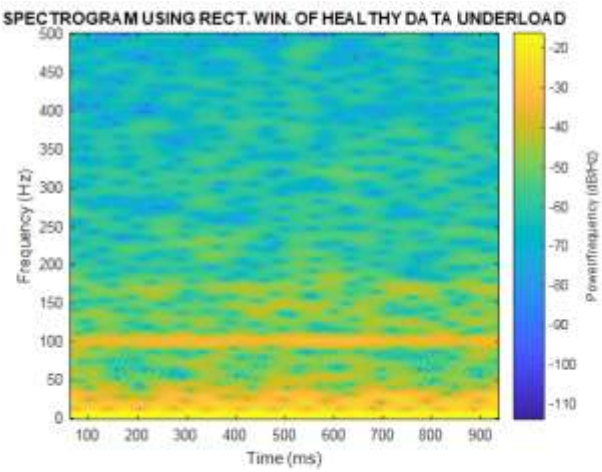

Figure8. Spectrogram of healthy time signal

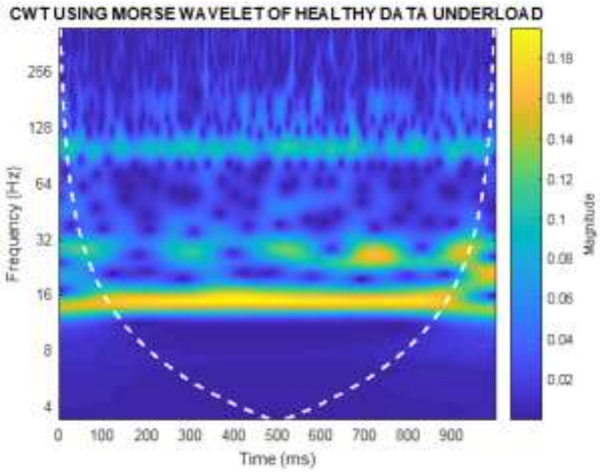

Figure9. Scalogram of healthy time signal

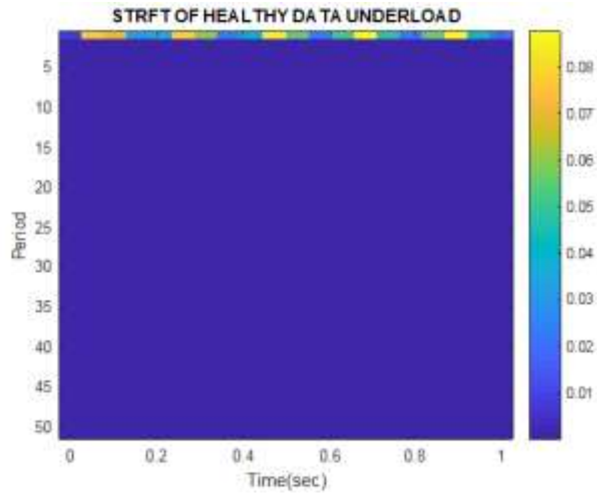

Figure10. ST-RFT using rectangular window

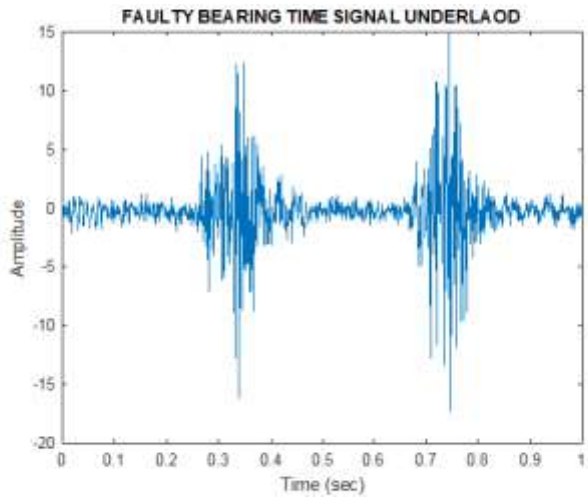

Figure11. Faulty time signal

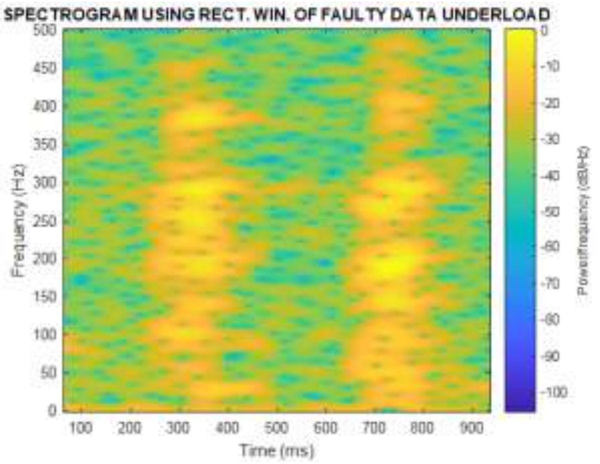

Figure12. Spectrogram of faulty time signal

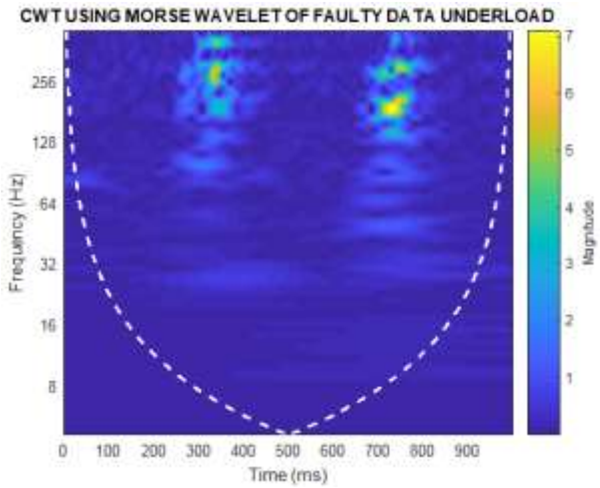

Figure13. Scalogram of faulty time signal

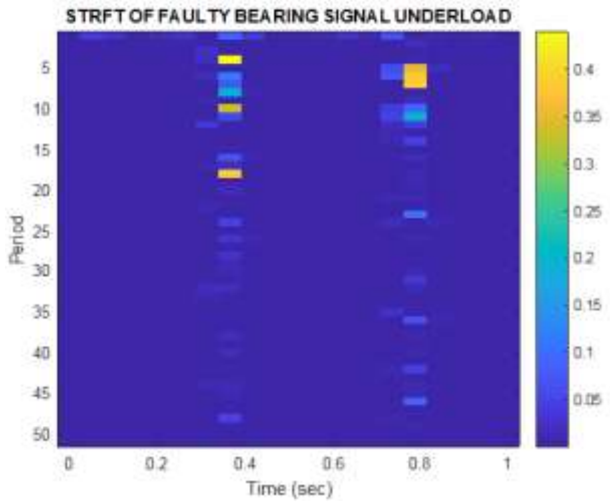

Figure14. ST-RFT of faulty time signal

V. Conclusion and Future Work

This paper present the machine condition monitoring of vibration signals based on ST-RFT. The test results validate the effectiveness of the proposed method in machine condition monitoring of vibration signals. The results can be affected by selecting of window size. Therefore the window size should be proper. In the paper we selected the window length of 51. The ST-RFT has been used to improve the results compare to STFT and Wavelet Transform with good resolution. The work can be further extended with de-noising of vibration signals by compressing sensing and singularity detection.

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