# Wavelet Transform And Envelope Detection For Gear Fault Diagnosis .A Comparative Study

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*Abstract*— **On-line vibration monitoring of Rotary Machines is a fundamental axis of development and industrial research. Its purpose is to provide knowledge about the working condition of machines at each moment without stopping the production line. This method allows avoiding the production losses related to breakdowns and reducing overall maintenance costs.**

**Bearing fault diagnosis is important in vibration monitoring of any rotating machine. Early fault detection in machineries can save millions of dollars in emergency maintenance cost.**

**This paper presents the comparison results of Fault diagnosis Techniques of gear fault using two methods: Envelope Detection (ED) and Wavelet Transform (WT) using Morlet Wavelet the comparative study is applied to real vibratory signals.**

***Keywords— Vibration Analysis; Fault diagnosis; Wavelet Transform (WT); Envelope Detection (ED);***

## I. INTRODUCTION

The condition monitoring is a fundamental axis of development and industrial research. Its purpose is to provide knowledge about the working condition of systems at each moment without stopping the production line. The monitoring allows avoiding the production losses related to breakdowns and reducing overall maintenance costs [1] [2]. Different methods are used in industry for condition monitoring: acoustic measurements, vibration measurements and, temperature measurements and wear debris analysis. Among these, vibration measurements are extensively used in the condition monitoring and diagnostics of the rotating machinery [3].

In order to obtain useful information from vibration measurements and provide aid in early detection and diagnosis of faults there are many signal analysis techniques like Fourier Transform (FT), Short Time Fourier Transform (STFT) [4]-[5], Wigner-Ville Distribution (WVD), Envelope Detection (ED) [9], and Wavelet Transform (WT) [7]-[8], [10]. The most of these methods use spectral analysis based on FT, therefore, these methods present some limitations; it is the inability of FT to detect non-stationary signals [10]. This inability makes wavelet transform an alternative for machinery fault diagnosis. The WT can be continuous or discrete. The Continuous Wavelet Transform (CWT) reveals more details about a signal but its computational time is enormous. For most applications, however, the goal of signal processing is to represent the signal efficiently with fewer parameters and less computation time. The Discrete Wavelet Transform (DWT) often called multi-resolution analysis can satisfy these requirements

The selection of the appropriate wavelet is very important in signals analysis. There are many types of wavelets available can be used such as Haar, Daubechies, Meyer, and Morlet wavelet. Different wavelets serve different purposes.

This paper presents the comparison results of Fault diagnosis Techniques of gear fault using two methods: Envelope Detection (ED) and Wavelet Transform (WT) using Morlet Wavelet ,the comparative study is applied to real vibratory signals

The paper is organized as follows. The next section presents the proposed Fault Detection Techniques for gear fault diagnosis. Presentations of the experimental test rig and gear fault description are proposed in Section 3. The monitoring results are discussed in Section 4, with a comparison between the monitoring capabilities of WT (Morlet) and Envelope Detection (ED). Finally, the concluding remarks are given in section 5.

## II. FAULT DETECTION TECHNIQUES

### A. Wavelet Transform (WT)

Wavelet Transform (WT) is a relatively new signal processing tool with strong capability in time and frequency domain analysis. It describes a signal by using the correlation with translation and dilatation of a function called mother wavelet. The WT includes Continuous Wavelet Transform (CWT) and Discrete Wavelet Transform (DWT).

The CWT of a given signal s(t) is defined by [8], [11], [12]

$$\mathrm{CWT}\ (a,b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} \mathrm{s}(t)\psi^*(\frac{t-b}{a})\,\mathrm{d}\,t \qquad (1)$$

Where, $\psi^*(t)$ is the conjugate function of the mother wavelet $\psi(t)$. The terms $a$ and $b$ are the dilation and translation parameters, respectively [8], [11].

The DWT is derived from the discretization of CWT (a, b). It is given by

$$\mathrm{DWT}(j,k) = \frac{1}{\sqrt{2^j}} \int_{-\infty}^{\infty} \mathrm{s}(t)\psi^*(\frac{t-2^j k}{2^j})\mathrm{d}t \qquad (2)$$

Where, $a$ and $b$ are replaced by $2^j$ and $2^j k$ [8].

The Discrete Wavelet Transform (DWT), often called Multi-resolution analysis [13], consists of the introduction of the signal to be analyzed into low-pass and high-pass filters. At this level, two vectors will be obtained. The vector elements $A_j$ are called approximation coefficients; they correspond to the lowest frequency signal, while the vector elements $D_j$ are called detail coefficients; they are corresponding to the highest of them. The procedure can be repeated with the elements of the vector and successively with each new vector obtained. The decomposition process can be repeated *j* times, with *j* the maximum number of levels. The wavelet transforms acts as a Mathematical microscope in which one can observe different paths of the signal by adjusting the focus [14]. The maximum number of decomposition level depends on the number of data points taken [15]. The principle of multi-resolution analysis is shown in Figure 1, and the detail $D_1$ in the range of 1–2 kHz. In the same figure, the procedure is repeated from $A_1$ to $A_4$ (four levels) [15], [17], [18].

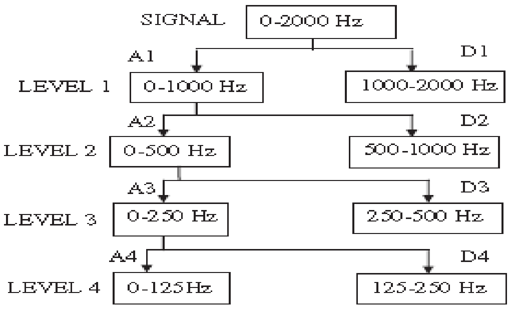


Figure 1. Principle of Multi-resolution Analysis

## B. *Envelope Detection*

The envelope detection or amplitude demodulation is an important signal processing technique enabling the extraction of the modulating signal from an amplitude modulated signal [19], [20], [21]. In the present work, Hilbert Transform is used to extract the envelope. Hilbert Transform in time domain, for a given signal x(t), is given by.

$$\hat{x}(t) = \frac{1}{\pi} \int_{-\infty}^{+\infty} \frac{x(\tau)}{t-\tau} d\tau \tag{3}$$

It is defined as the convolution of the signal x(t) with function 1/πt, which is the impulse response function of the Hilbert Transformer. The phase shifted and original signals are summed up to obtain an analytic signal x+(t) defined as follows [22], [23], [24].

$$x_+(t) = x(t) + j\hat{x}(t) \tag{4}$$

The envelope of the signal is defined as [25], [26].

$$v(t) = \sqrt{x_+(t)^2 + x(t)^2} \tag{5}$$

The process of the envelope detection is involved from three main steps; The First step is signal filtering with a band-pass filter, the next step is the envelope extraction of band-pass filtered signal using the Hilbert transform, the final step is the extraction of frequency spectrum of the envelope signal using the Fast Fourier Transform (FFT) [25].

# III. EXPERIMENTAL STUDY

## A. *System Description*

The experiments presented in this paper used the vibration data obtained from a test rig located at Iron and steel applied research unit URASM/CSC, Annaba, Algeria. This test rig is shown schematically in Fig.2.It permits to introduce the principal faults existing and to acquire measurements relating to these various faults.

It consists of two gears 1 and 2 (1 with 60 teeth and the other with 48 teeth), four bearing housings (H1, H2, H3 and H4), coupling and disk. The system is driven by a 0.18 kW induction motor controlled by variable speed drive (0-1500 rpm).

The multi-channel system of acquisition OR25 permits the registration of the vibratory signal according to time and to frequency. The configuration of the multi-channel system is needed before to start the acquisition.

The piezoelectric accelerometers were attached in two directions for measurement of vibration. The signal is transmitted to a transducer pre-amplifier. The output of the pre-amplifier signal is transmitted according to time and to frequency using the FT analyzer of OR25. These instruments will give the necessary information about the rotating machine conditions.

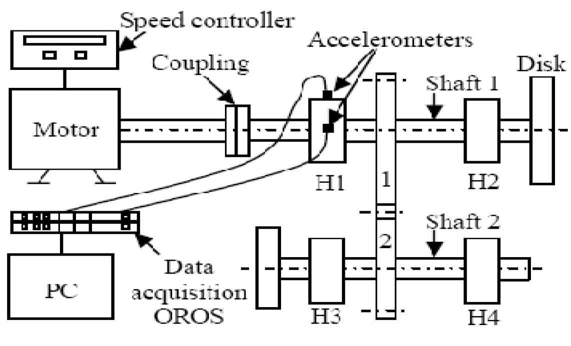


Figure 2. The test-bed to simulate the fault of gear

### *B. Fault gear Characteristic Frequencies .*

The purpose of gears is to transmit and transform rotary motion from one shaft to another. The vibration monitored on a faulty gear generally exhibits a significant level of vibration at the tooth. Gear Meshing Frequency GMF (i.e. the number of teeth on a gear multiplied by its rotational speed) and its harmonics of which the distance is equal to the rotational speed of each wheel as shown in Fig.4 [10].

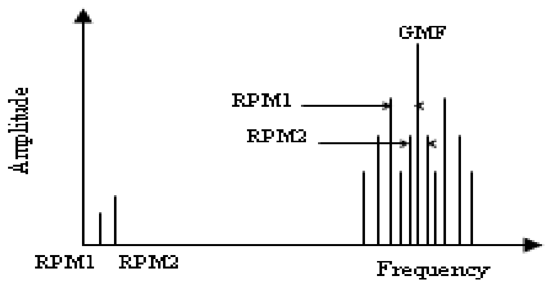


Figure 3. Frequency spectrum of gear fault

In our experiment, the gear fault is produced mainly by the shock between the teeth of the two gears 1 and 2. The GMF is defined as [10]

$$F_{GMF} = f_1 N_{R1} = f_2 N_{R2} \qquad (6)$$

Where $f_1$ is equal to motor and shaft 1 frequency. As shown in Fig.5, the vibration signals of gear fault were taken on bearing housing H1 of the shaft1 through piezoelectric accelerometers mounted in Horizontal and Vertical Directions (HD and VD).

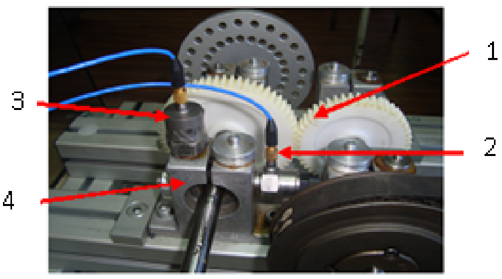


Figure 4. Location of piezoelectric accelerometers

1-Gears
2- Piezoelectric accelerometers type 288D01 in HD
3- Piezoelectric accelerometers type 353B34 in VD
4-Bearing housing H1

## IV. RESULTS AND DISCUSSIONS

These measurements were repeated for different states of the system at the frequencies; 17.5Hzand 25Hz in VD and HD, respectively.

The number of data points or samples for each signal is 2048.

In the two cases; normal and faulty, the vibration signals are collected at a speeds of 1050 rpm (17.5Hz) and 1500 rpm (25Hz).

Fig.6 represents the time domain vibration signals of normal state (Fig.6a to Fig.6d) and vibration signals of gear fault (Fig.6e to Fig.6h) in VD and HD.

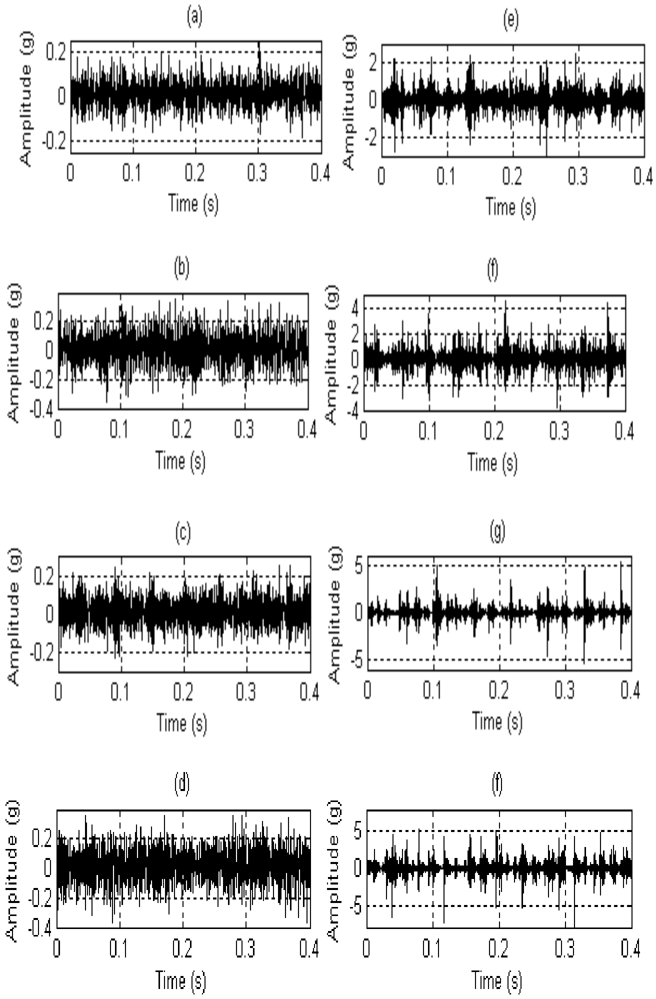


Figure 5.Vibration signals of normal and fault states at two rotation speeds (17.5Hz and 25Hz)

The Fig.6 represents the spectrums of gear fault using Envelope Detection (ED) at 17.5Hz , 25Hz and in HD and VD..

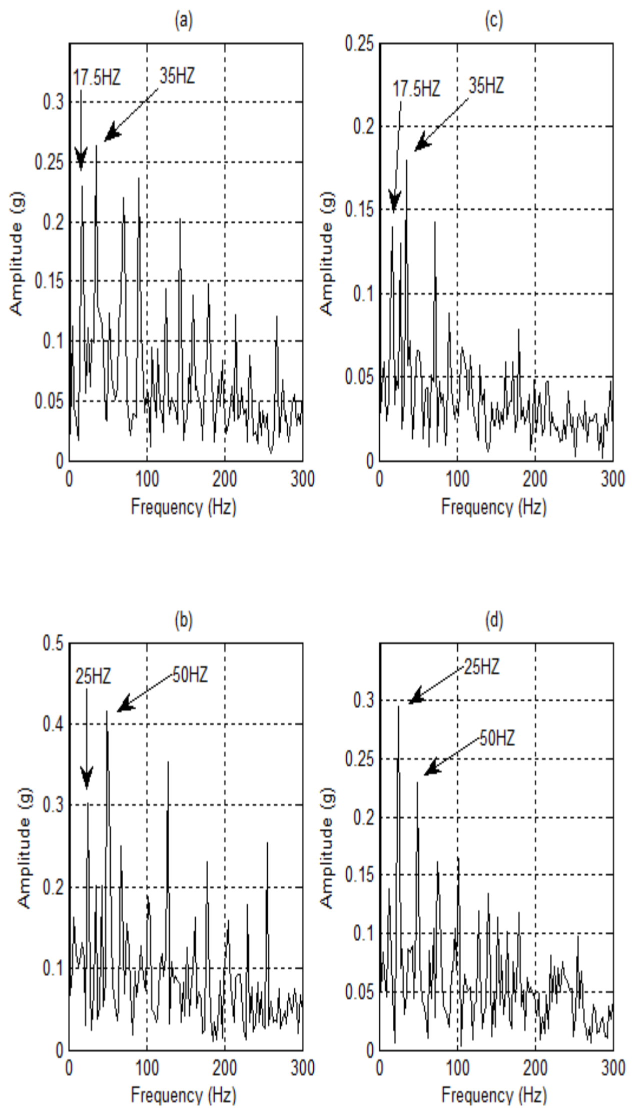


Figure6. Spectrums of gear fault using Envelope Detection at 17.5Hz and 25Hz speeds

From Fig.6, it was observed the presence of significant peaks at the rotation frequencies of the shaft1 (17.5Hz and 25Hz) and its multiples, both in HD (Fig.6a, Fig.6b) and VD (Fig.6c, Fig.6d) which indicates a gear fault.

The Fig.7 represents the spectrums of gear fault using WT (Morlet ) at 17.5Hz , 25Hz and in HD and VD.

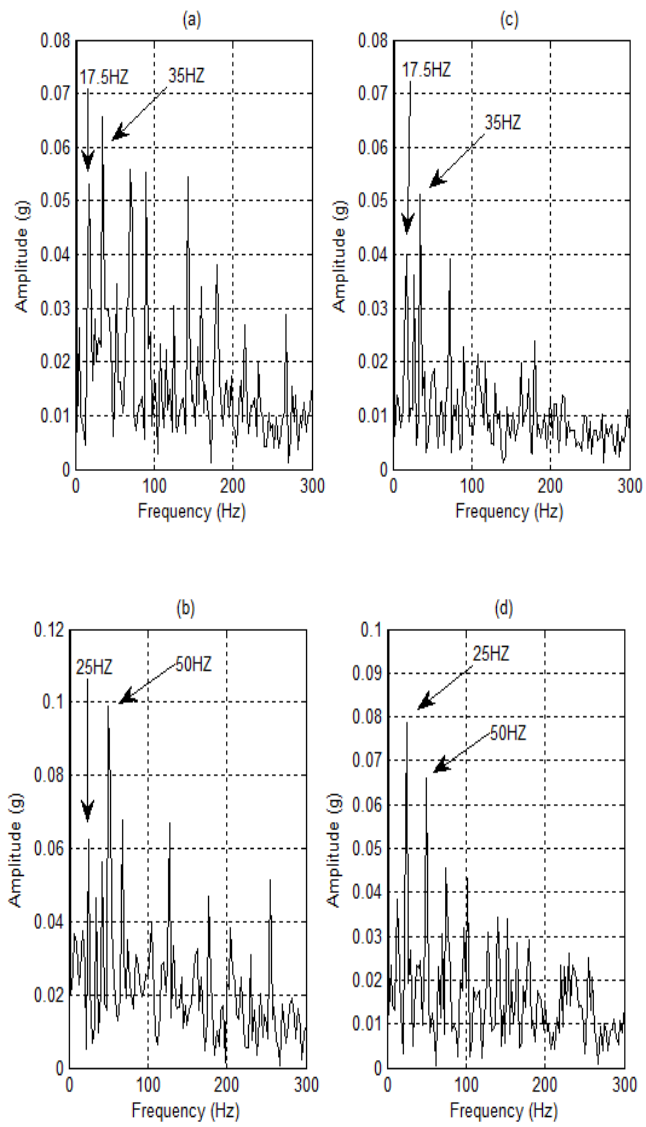


Figure 7. Spectrums of gear fault by (WT) using Morlet wavelet at 17.5Hz and 25Hz speeds

From the Fig.7, it is clearly shown that the peaks at the rotation frequencies of the shaft1 17.5 and 25 Hz in HD (Fig.7a, Fig.7b) and VD (Fig.7c, Fig.7d) and their multiples are present in the frequency spectrum which confirms the presence of a gear fault.

For a better appreciation of the performance of the best method, we have presented in Fig.8 a comparison of the peaks of gear fault at the rotation frequencies of the shaft1 17.5 and 25 Hz in HD and VD for different methods ED and WT (Morlet).

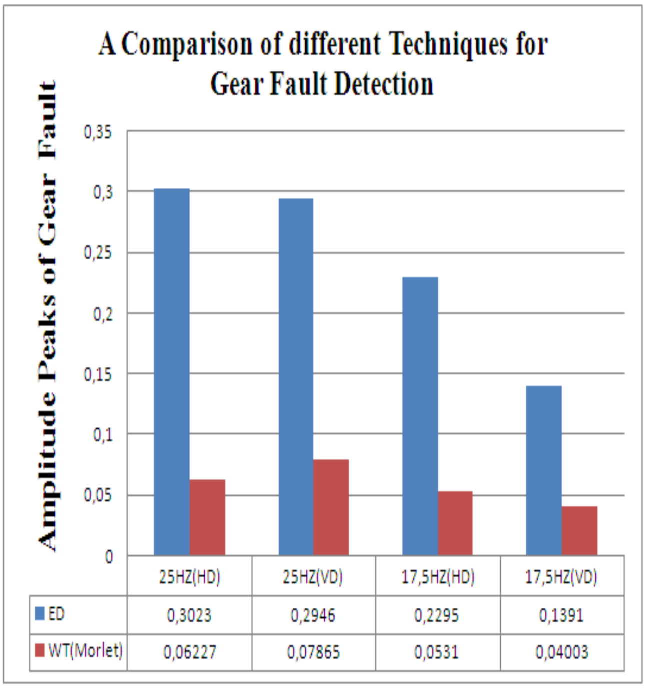


Figure 8.Peaks Comparison of Gear Fault for different Techniques

From the comparison of the results shown above, we can note that:

- Spectrums of a gear fault obtained by WT (Morlet) wavelet shows small increase in peaks amplitude at the rotation frequencies in HD and VD and its harmonics, which make difficult the identification of gear faults.

- Spectrums of a gear fault obtained by using ED shows a considerable increase in peaks amplitude at the rotation frequencies in HD and VD and its harmonics, which enhances the gear fault identification relatively to WT.

## V. Conclusion

This paper presents the comparison results of Fault diagnosis Techniques of gear fault using two methods: Envelope Detection (ED) and Wavelet Transform (WT) using Morlet Wavelet, it is evident that both the methods of are effective to identify gear defect, but Envelope Detection (ED) gives excellent results relatively to the Wavelet Transform (WT) using Morlet Wavelet in this case when the gear fault is produced mainly by the shock between the teeth of the two gears

It remains to test its feasibility on other types of faults in rotating machinery.

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