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DIAGNOSIS OF GEARS SYSTEM WITH SENSITIVE INDICATORS

Ishak TOUAFEK(1)(*), Ahmed FELKAOUI(1) , Hafida MAHGOUN(1), Nassira LAISSANI(1)
(1): Optics and precision Mechanics institute University Ferhat Abbas – Setif - (Algeria).
(*) touafekishak@yahoo.com

ABSTRACT

Indicators measure the vibration or describe the condition of a machine. They shed light on trends that may lead to damage, they describe the deviation of the health status relative to a reference state.

Indicators must satisfy a number of qualities that can sometimes be contradictory, such as: relevance, simplicity, objectivity, sensitivity, accuracy, reliability, robustness, etc..

The sensitivity of the indicators is the ability of these to detect any presence of a defect in the mechanical parts. It plays a very important role in the early detection and diagnosis of faults or failures in rotating machinery. Several researchers have focused on improving the sensitivity, we find, among others, in the case of filtering , de-noising, the time synchronous averaging , the correlation and envelope spectrum , etc..

This work aims to study and compare the sensitivity of statistical scalar indicators of mechanical shock (kurtosis, crest factor) applied to signals which have been decomposed by the empirical mode decomposition (EMD) to increase their sensitivity.

Key words: signal processing, faults diagnosis, Emprical Mode Decomposition (EMD) , Kutosis, crest factor.

1- INTRODUCTION

Vibration monitoring using scalar indicators such as kurtosis, crest factor based on their sensitivity to detect a malicious purpose machines defects during operation. For this, the application of some methods can help to increase the sensitivity by eliminating some non significant signals mixed with in the original signal recorded using accelerometers sensor.

Because these signals include the signals of gears, rolling bearings, etc ... ... and to monitor these elements, one must know the special characteristics of each element that makes up the machine.

In our case, the diagnosis is made on the gears. We used the gear signals of CETIM laboratory in France to implement the methods we used.

In this work, we will give the signal characteristics of gear, simulating a signal with his meshing frequency and rotating frequency. The method we used is method that have given perfect analysis for non-stationary and non-linear signals using the empirical mode decomposition (EMD).

2- GEARS

2-1 Definition

The gear is one of the power transmission largest used in construction of rotating machines.

Gear consists of the set of two gears meshing with each other to transmit power between two shafts close together with a constant gear ratio.

When a gear is defective, he generates shocks which can be seen on the spectrum of the signal that represents and its, in general, with the form of non-stationary.

Also the spectrums measured on the machines that are equipped are rich in harmonic frequencies that we will be defining below.

2-2 Meshing frequency

We have a gear with two pinions 1 and 2, with Z1 and Z2 teeth and turning frequencies F1 and F2. Each time a teeth of the wheel engages in leading a driven wheel 2, there is a charging jack periodic rate of engagement of the teeth meshing with a frequency Fe equal to the frequency of rotation of the wheel multiplied by the number of teeth.

$$f_e = f_1 \times Z_1 = f_2 \times Z_2 \qquad (1)$$

If the teeth are correct, the spectrum consists of components whose frequencies correspond to the meshing frequency and its harmonics.

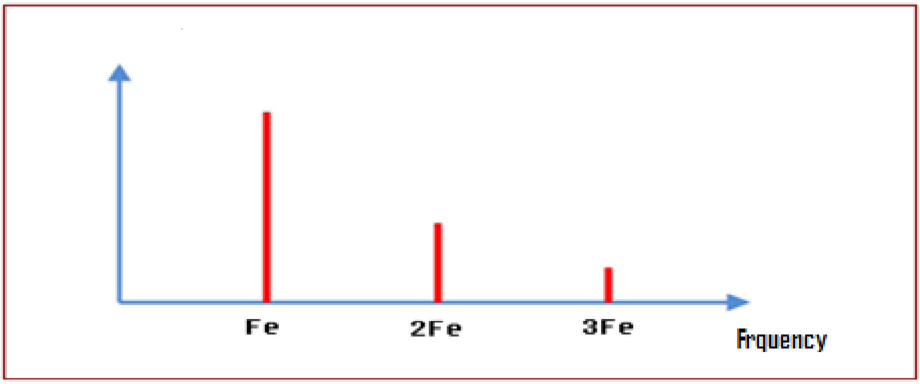


Fig.1 Spectrum of correct gear

2-3 Modeling of a gear:

2-3-1 Mathematical model of gear faults

If we consider a gear vibration signal which is averaged synchronously with respect to the frequency fr of rotation of a wheel of teeth Z, we will have:

$$y(t) = \sum_{m=0}^{M} X_m \cos\left(2\pi m Z f_r\, t + \emptyset_m\right) \qquad (2)$$

M : order signal analysis of meshing.
X_m the amplitude of the harmonic *m*.

If the gear now has a defect, such as a crack at the base of teeth, this will result in an amplitude modulation and phase signal meshing. The modulated signal is given by

$$y(t) = \sum_{m=0}^{M} X_m \left(1 + a_m(t)\right) \times \cos\left(2\pi m Z f_r t + \emptyset_m + b_m(t)\right) \qquad (3)$$

$$a_m(t) = \sum_{n=0}^{p} A_{mn}.\cos\,(2\pi n f_r t + \alpha_{mn}) \tag{4}$$

$$b_m(t) = \sum_{n=0}^{p} B_{mn}.\cos\,(2\pi n f_r t + \beta_{mn}) \tag{5}$$

$a_m(t)$ and $b_m(t)$ represent respectively the amplitude modulation and frequency signal meshing due to the presence of a defect of teeth. These functions are defined by their Fourier series.

In the spectrum, the amplitude modulation will create lines around the side peaks meshing. The spacing of the satellite lines is equal to the frequency of rotation of the wheel bearing failure. The extent of the satellite lines depends strongly on the shape of the modulating signal.

It can therefore be based on the assumptions above, to a demodulation of amplitude and phase of the signal $y_m(t)$

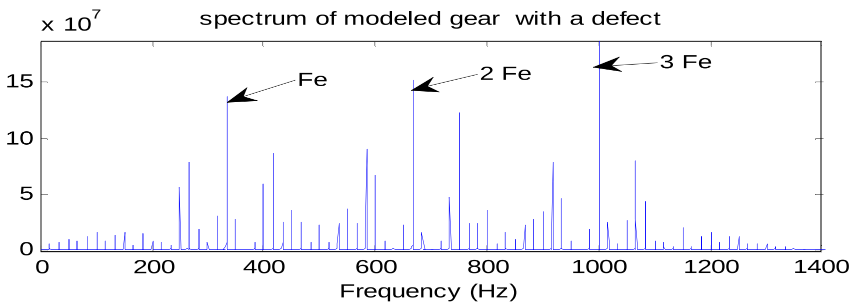


Fig.2 simulated spectrum of a gear

We see in the figures (2), the spectrum of a gear modeled with a defect. This spectrum shows the peaks of the meshing frequency and its harmonics, in addition to the side stripes representing the frequency of rotation around the meshing frequency.

For the presence a defect, the signal failure of the gear change at the side stripes that will increase in amplitude.

3- EMPIRICAL MODE DECOMPOSITION (EMD) :

The technique of Empirical Mode Decomposition (EMD) is a signal analysis method that was introduced by **Norden Huang**. Applied since (1998) to decompose any signal into a sum of oscillating components derived directly from it.

These components (or IMF for “Intrinsic Mode Functions”) are interpreted as non-stationary waveforms, (modulated in amplitude and frequency) may optionally be associated with non-linear oscillations.

IMF satisfying the conditions

1- In the whole data set, the number of extrema and the number of zero-crossing must either be equal or differ at most by one.
2- At any point, the mean value of the envelope defined by local maxima and the envelope defined by the local minima is zero.

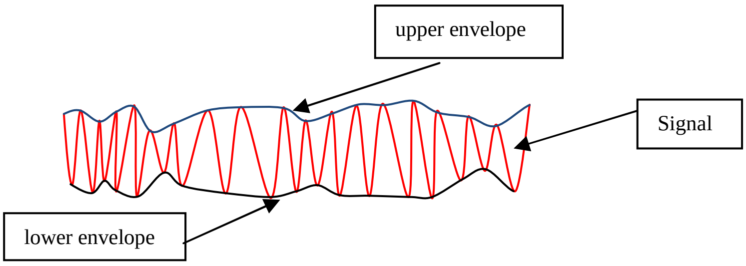
The empirical mode decomposition is a method of deflation is an iteration in which each estimate is subtracted from the signal mode and analyzed or estimate the next mode is driven from the signal residue.

3-1 The EMD method.

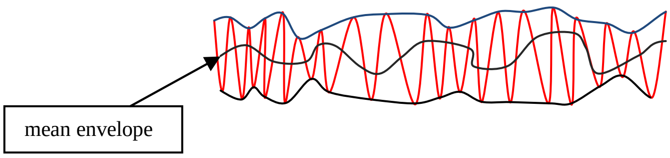
An IMF represents a simple oscillatory mode as a counterpart to the simple harmonic function of the Fourier series method. To obtain an IMF from the original signal, we do the following steps:

Pick out all of the maxima of the series signal X(t) and calculate the upper envelope with cubic spline function.

Pick out all of the minima of the series signal X(t) and calculate the lower envelope with cubic spline function.



The mean envelope m1(t) of the signal X(t) is the mean value of the upper envelope and lower envelope.



A new series h_1 with low frequency removed is calculated by subtracting the mean envelope from the serie X(t):

$$h_1(t) = X(t) - m_1(t) \tag{6}$$

4Generally speaking, h_1 is still a non stationary series, so the above procedure must be repeated “k” times until the mean envelope is approximate to zero, so the first IMF component C (t) is obtained:

$$h_{1(k-1)}(t) - m_{1(k)}(t) = h_{1(k)}(t) \tag{7}$$

$$C_1(t) = h_{1(k)}(t) \tag{8}$$

The first IMF component represents the highest frequency component of the original series.

The second IMF component C_2(t) can be obtained from the margin series r_1(t) which is calculated by subtracting the first IMF component from series X(t). such procedure needs to be repeated until the last margin series r n(t) cannot be decomposed, here rn(t) represents the mean value or trend of original series.

$$r_n(t) - C_2(t) = r_2(t) \dots \dots \dots . r_{n(n-1)}(t) - C_n(t) = r_n(t) \qquad (9)$$

So, the original series can be presented as:

$$X(t) = \sum_{j=1}^{n} C_j(t) + r_n(t) \qquad (10)$$

4- STATISTICAL INDICATORS

4-1 Kurtosis :

This quantity introduced by the mathematician Pearson is deduced by the ratio:

$$Kurtosis(sig) = \frac{M_4(sig)}{[M_2(sig)]^2} \qquad (11)$$

M_4 (sig) and M_2 (sig) are respectively the moments of order 4 and 2 signal (sig).

For a Gaussian distribution, the kurtosis has a value of 3, then for the presence of a default, it takes a value greater than 3.

4-2 Crest factor :

The crest factor is defined as the ratio between the peak (max) in signal and RMS (RMS)

$$F_{crete} = \frac{V_{crete}}{RMS} \qquad (12)$$

This indicator is used to detect specific pulse or shock present in the vibration signal.

For a Gaussian distribution, the crest factor of 3 to 6, but for the presence of default, this flag is set higher than 6.

5- GEAR SIGNALS OF CETIM

The system consists of a motor, a gear ratio of 40/42 and closure of the gear tested, report 20/21. Figure (3) shows the system.

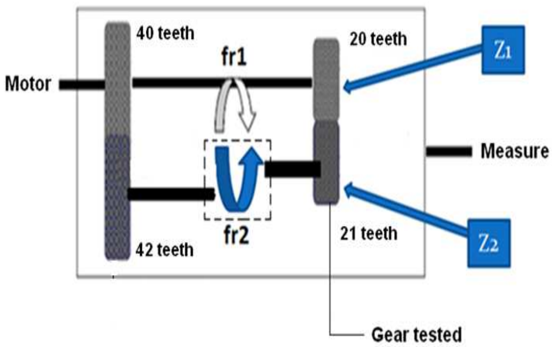


Fig.3 System of CETIM

The table (1) gives the characteristic of the system tested with CETIM

Table 1 Characteristic of the chassis CETIM

Sampling frequency	**Fs**	**20000**
Number of points recorded	N	60170
Meshing frequency (Hz)	fe	333.48
Number of teeth of the pinion 1	z1	21
Number of teeth of the pinion 2	z2	20
Frequency of rotation of the pinion 1 (Hz)	f1	16.67
Frequency of rotation of the pinion 2 (Hz)	f2	15.88

. Table 2 Expert report

Day	Observation
2	First day of acquisition, no anomaly
3	no anomaly
4	// //
5	// //
6	// //
7	Scaling in the teeth 1/2
8	No change
9	tooth 1 / 2 no change
10	Evolution of tooth scaling 15/16
11	// //
12	// //
13	Scaling across the width of the tooth 15/16

The analysis of time signals allows us to visualize the occurrence of a fault very marked the twelfth day. However, as can be seen in figure (4), it is not possible to detect early the occurrence of a fault using the time signals.

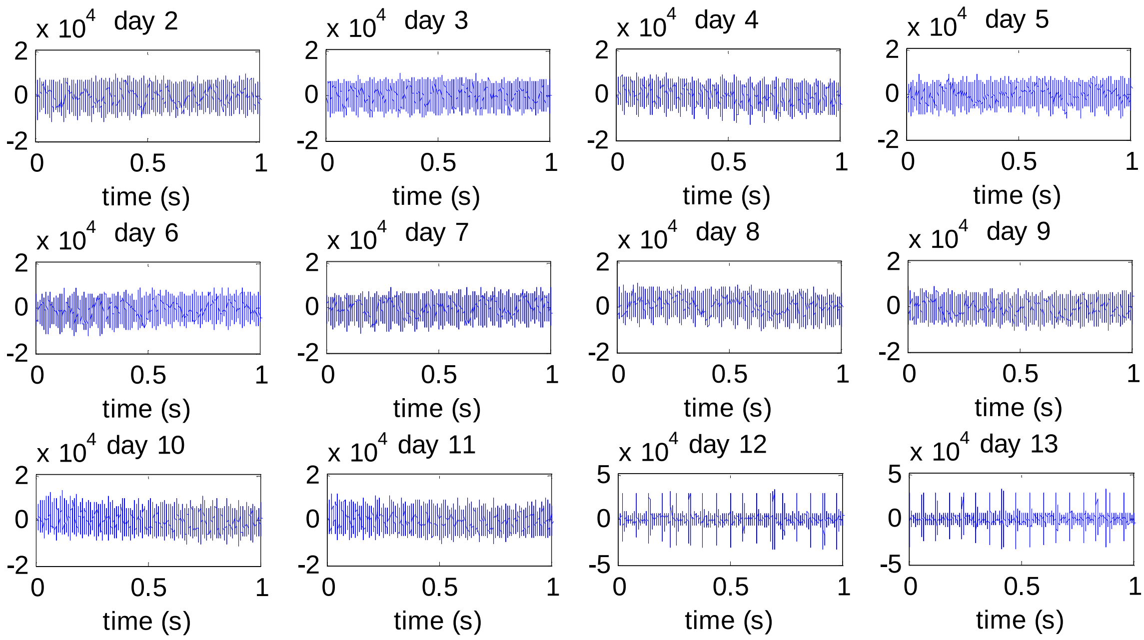


Fig.4 Time signals of the gear train CETIM

The calculation of statistical indicators for the 12 days of the experiment back to draw the curves in the following figures.

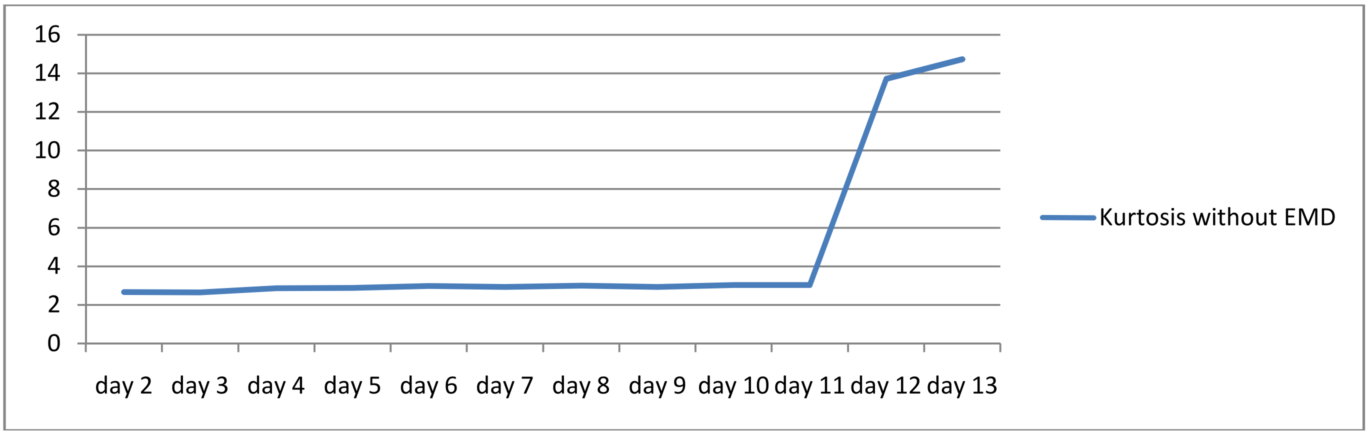


Fig.5 kortosis in 12 days

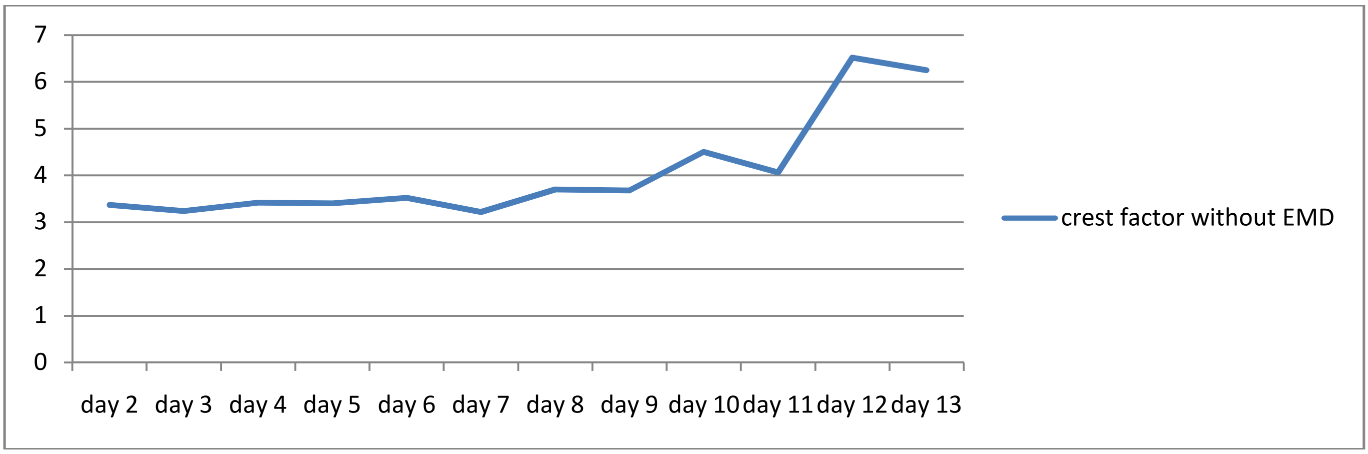


Fig.6 Crest factor in 12 days

6- APPLICATION OF EMD ON THE SIGNALS CETIM

The EMD method decomposes the signal into several signals in mono mode known IMF. And each IMF covers a frequency band, it acts as a filter band (strip).. The decomposition process of high frequency to lower frequencies. In what, monitoring indicators are calculated by taking the total size of the signal and not around the frequencies selected such as meshing frequencies.

The table (3) shows the frequency band of each IMF around the maximum frequency for signals of CETIM.

Table 3 Frequency bands of each IMF

IMF	Bande fréquentielle [Hz]
1	2950 - 3150
2	1270 - 1440
3	610 - 780
4	230 - 400
5	200 - 400
6	200 - 400
7	50 - 150
8	20 - 120
9	0 - 50
10	0 - 35
11	0 - 10
12	0 - 10

IMF 5 shows a spectrum represents the meshing frequency

IMF 4 and IMF 3 present a spectrum which shows the second harmonic of the meshing frequency.

IMF 9 et IMF 10 show the spectrum of rotating frequency

IMF 8 shows the spectrum of the third harmonic of rotating frequency.

Le signal reconstruit à partir de ces IMFs est de la forme suivante :

Defects found in the gears are kind of shock, then most of the monitoring indicators used for this type is the Kurtosis and crest factor.

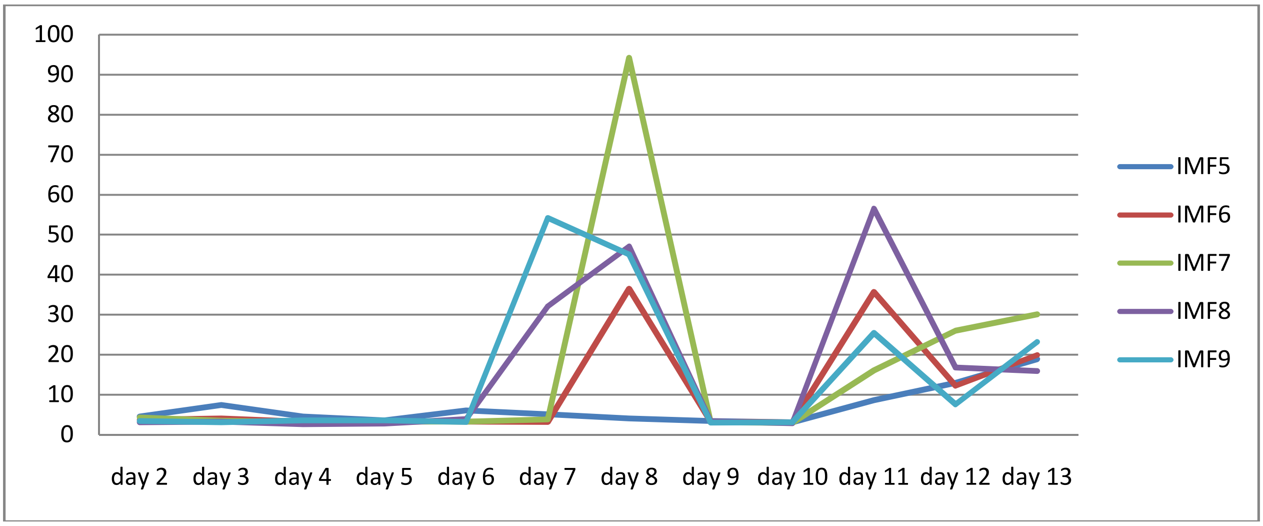


Fig.7 Variation of kortosis for IMF of 12 days

Figure (7) shows the distribution and variation of the kurtosis of each IMF during the 12 days of testing. We see that this indicator reach the value (54) on day 7 and (96) for the IMF 7 and (47) for the IMF 8 and IMF 9 on the day 8..

We can say that the fault has occurred from day 7. But, before the use of EMD, the variation of kurtosis shows that the fault has occurred in the 12 days.

Figure (8) shows a comparison of the variation of kurtosis in the 12 days before and after the application of EMD.

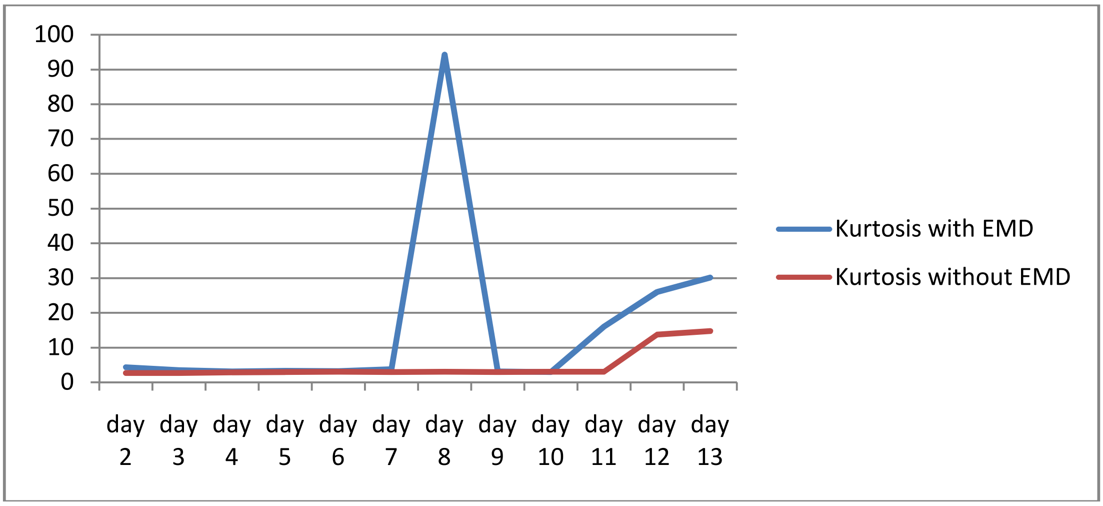


Fig.8 kurtosis in 12 days with EMD and without EMD

We clearly see the increased sensitivity of this indicator on the days 7, 8, 11, 12, and 13 after application of EMD.

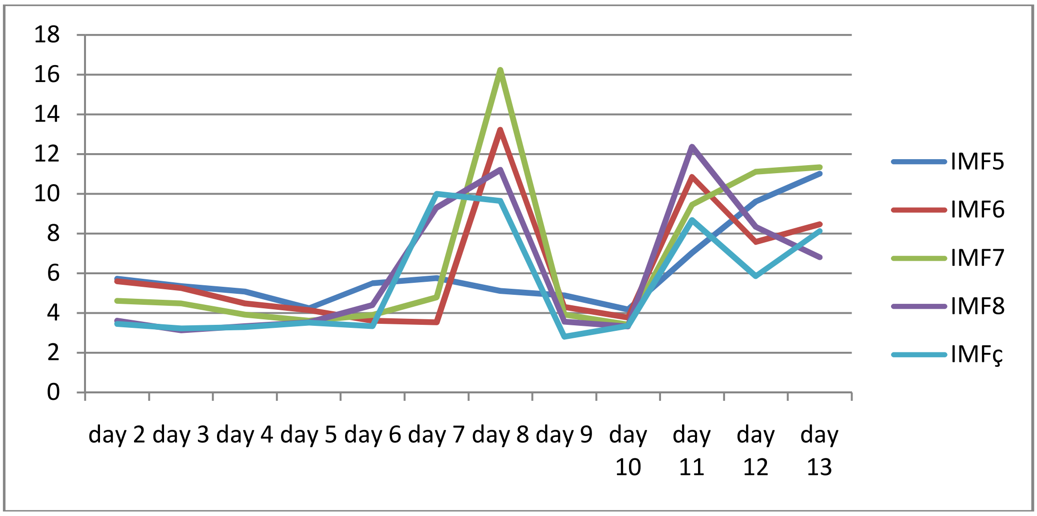


Fig.9 Variation of crest factor of IMF in 12 days

The application of the method of empirical mode decomposition (EMD) has detected the presence of a fault on the day 7 and not on the day 12.

The value of crest factor is close to 10 for the IMF 8 and IMF 9 on the day 7, and on the day 8, this value is increased to 16 for the IMF 7.

Figure (10) shows a comparison of the change in this indicator before and after the application of EMD.

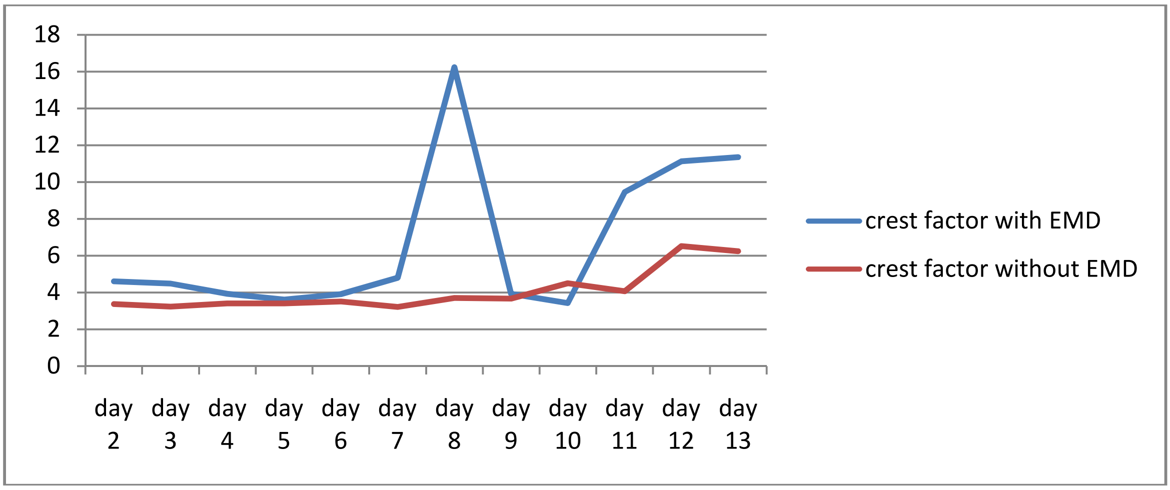


Fig.10 Crest factor before and after the application of EMD

The sensitivity of this indicator is also increased with the use of EMD.

7- CONCLUSION

In this work, we applied methods for non-stationary signals and non-linear in order to see their effect on the sensitivity of statistical indicators for monitoring such as kurtosis and crest factor.

The method of empirical mode decomposition (EMD) is applied to the test signals for broken down into several IMF to represent the frequency bands exist in the original signal.

With this technique, we have seen that the shock-like defects, occurred in the seventh day and not the twelfth day, which shows that the sensitivity of the indicators used for this purpose given to increased and improved monitoring and diagnostic reading.

The method of the EMD, and as it is based on a specified algorithm is not a well defined theory such as wavelets.

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