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The empirical mode decomposition (EMD) application for the monitoring of the cutting tools wear

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ABSTRACT: In this work, it is a question of the cutting tool wear monitoring in mechanical turning. We did this monitoring in three phases which correspond to the life of our tool. To achieve this objective of improving monitoring, we have used a processing method (EMD) that breaks down a large signal into small signals (IMFs). The cut up or processed signals are yet applied in the temporal (RMS) and frequency (Spectrum) indicators in order to monitor the evolution of the tool in relation to its degradation and to check the reliability of the indicators. The obtained results will be optimized in an on-line monitoring system and incorporated into a microcontroller dealing with its three phases, in order to make the comparison of informations each time they are generated by the machine.

KEYWORDS: mechanical turning, vibratory analysis, wear, EMD, IMF, monitoring, sieving, indicators.

1 INTRODUCTION

Machining by material removal remains the most widely used process in the mechanical industry in a wide range of applications (from aerospace to automotive industry). The cutting tool wear represents yet one of the major factors when requiring higher productivity associated with better quality of the manufactured products. Thus, it is necessary to have a thorough knowledge of the cutting process [1]. Indeed, the wear phenomenon is progressive and develops itself during the cutting process, which damages the quality of the machining. The degradation of the tool condition also damages the quality of the machined surfaces, the imposed geometric tolerances, the tool's durability and generates high efforts having as effect: the increase of the cutting power and the consumed energy [2].

In this context, the cutting tool monitoring is the approach proposed in this work. It consists in processing the vibrations generated during the three phases of the tool in machining, using simultaneously frequency and temporal analyses by Empirical mode decomposition method (EMD) which is a method of multi-resolution decomposition of signals in intrinsic mode functions (IMF). The objective of these analyses is to follow the evolution of the cutting tools wear during their three phases. Through this EMD method (Empirical Mode Decomposition), the cutting process monitoring is made necessary and uses very robust and reliable methods of supervision of tools states. This method is very necessary and important for identifying and locating the tool wear in the machining process [3].

2 STATE OF THE ART

In recent years, most scientific researchers have addressed the subject on signal processing in order to follow the evolution of industrial materials. Some of them are: Bovic Kilundu Y'ebondo who speaks on singular spectral analysis (SSA) which is a non-parametric technique of temporal series analysis. It allows the decomposition of a signal into independent signals, which sum gives the original signal [4]. W. Rmili has spoken on the study of developing a process for processing vibratory signals in order to develop a monitoring system capable of improving the machining performance. To achieve his objective, he has used temporal analysis and frequency analysis of vibratory signals that allowed him to extract a set of parameters that could be subsequently considered as wear indicators [5]. J. Ladies has spoken, in the 19th Mechanics French Congress, on the identification of weak nonlinearity in the vibrating systems from temporal data. He proposed two methods: the first method is based on the analysis of the nonlinear space state model from the vibrating system and the second method based on the analysis of the wavelet transform of temporal data [6]. Bouchra Abou El Anouar who speaks on the comparison and evaluation study of the effectiveness of monitoring and detection control methods of bearings defects: the vibratory analysis and the infrared thermography. It determines their detection limits and their complementarities. To do this, different tests are performed on ball bearings with a crack [7].

3 METHODOLOGY

3.1 EMD METHOD (EMPIRICAL MODE DECOMPOSITION)

The EMD method was introduced in 1998 by Huang et al. It is a local, iterative and adaptive decomposition. It is based on a process called *sifting* which allows to decompose a signal into basic contributions called empirical modes or IMFs (Intrinsic mode functions) which are single-component AM-FM signals (in the large sense), each with zero mean. The IMFs extraction is nonlinear, but their recombination for the exact reconstruction of the signal is linear. Based essentially on the natural signal variations or oscillations, the EMD allows an interpretation of the present physical phenomena. In addition to its implementation simplicity and its ability to describe punctually and instantaneously the not resolved frequency phenomena by Fourier analysis, the EMD is well adapted to the study of non-stationary signals generated by non-linear systems. Unlike other methods, the EMD method directly constructs the basic functions from the signal itself [3].

$$s(t) = \sum_{j=1}^{n} IMF_j(t) + r(t)$$

Where:

- $IMF_j\ (t)$ is the j^th oscillation,
- r (t) is the residual of the decomposition,
- n is the number of IMFs.

3.2 EMD ALGORITHM

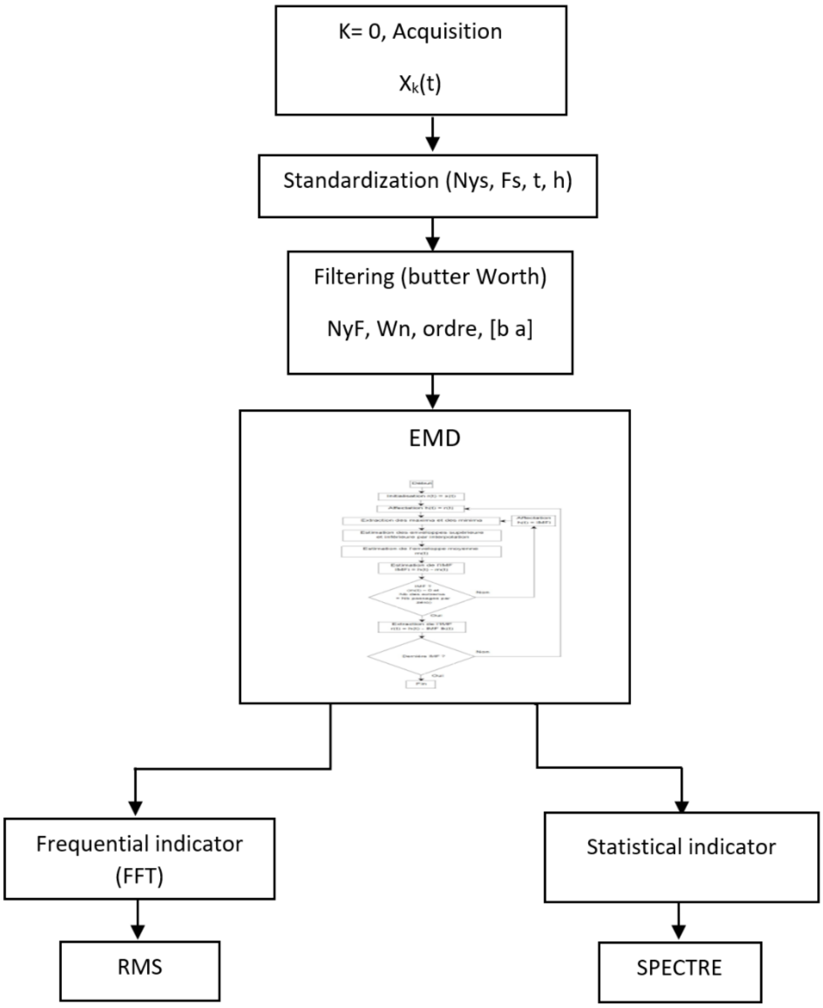

Fig. 1. Algorithm EMD

3.3 EXPERIMENTATION (EMD APPLICATIONS)

During this experimentation, we will apply the EMD method on real signals in order to see the capacity of the said method to detect the presence of wear on the cutting tool in an early and local way. The vibratory signals that we propose to study were carried out in the mechanical workshop of High Institute of Applied Techniques (ISTA) with equipments used to monitor the evolution of wear during machining. During this experiment, the tool passes from the state of good operation (new state) to that of the worn tool (advanced wear). The purpose of this experiment is to monitor the tool in these three (3) stages: new state, low wear, and advanced wear in order to detect the wear before the tool even goes bad for making the diagnosis of these defects. The statistical indicators are used in the IMF3 to have the tool states in relation to the wear with the help of the EMD method. Finally, we have applied the Fourier Transform in the original signal, IMF 1 and IMF 3 as well as the statistical indicators in order to represent the spectrum of these signals.

3.4 MATERIALS USED

3.4.1 MACHINE TOOL

The machine used to perform our tests is a Gallicop brand universal parallel lathe. It has the following characteristics:

- Cutting speed range: 10 to 400 m/min,
- Rotation speed range: 40 to 2000 rpm,
- Diameter range: 10 to 400 mm

Fig. 2. Chariot tower

These tests were carried out on this universal parallel lathe, using a cutting tool SCLCR1616H09 carrying a metal carbide insert, the material used for wear is a cylindrical shape of hard steel with a diameter of 50 mm.

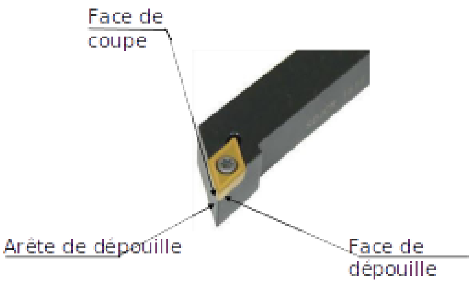

Fig. 3. Presentation of faces and edges

3.4.2 ACQUISITION CHAIN

The vibratory signals generated during machining were measured by using an acquisition and analysis system, composed of software and a piezoelectric accelerometer (X, Y, Z) compressed by a moving mass solicited by the vibrations to which the sensor is subjected. For a good acquisition, the PCB 080A27 sensor has been placed as close as possible to the machining area and on a fixed location as shown in 2.

In the case of our work, we have chosen the perpendicular axis in relation to the piece (the axis: X) that corresponds to the operation carried out, sliding to record more information.

This chain is composed of:

- The laptop, to visualize the signals.
- The cDAQ acquisition system + the NI 9171Module.
- The piezoelectric sensor.

Fig. 4. Acquisition chain

The vibration measurements are obtained by using the cDAQ acquisition system + the NI 9171 Module of National instrument, on which the NI9215 module with the BNC connector is mounted (Figure **5**).

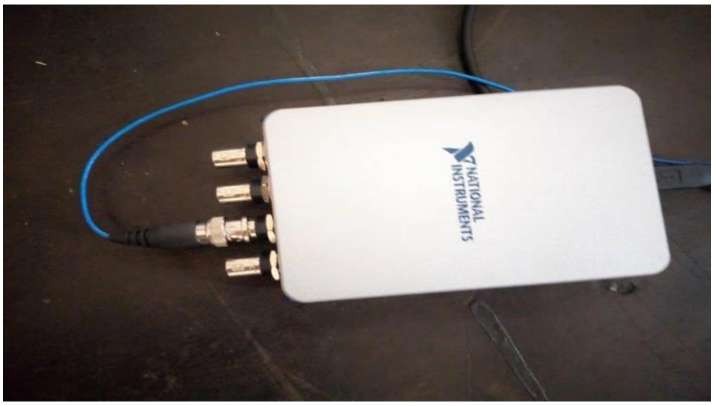

Fig. 5. Système d'acquisition cDAQ avec module 9215

A piezoelectric accelerometer (X, Y, Z) is attached to the upper carriage of the undercarriage by using a base compressed by a moving mass solicited by the vibrations to which the PCB 080A27 sensor is subjected with a sensitivity of 100 mV/g.

Fig. 6. IMI635A01 Accelerometer

The vibrations are sampled at 10000 Hz. Signals are recorded after a few seconds to detect any changes in the vibratory signal due to the evolution of the tool wear.

4 Data Analysis And Discussion Of Results

4.1 EMD Applied To Vibration Signals

As the signal is noisy, the EMD application yielded 6 IMFs with a residual in each phase of the tool. It shows that the noise contains high frequencies. This decomposition, gives the two IMFs (IMF 1 & IMF 3) containing the information of the tool degradation. The other IMFs are decomposed with the residuals, because they do not give any information. From this decomposition, we have represented the spectrum of the IMF3 frequency.

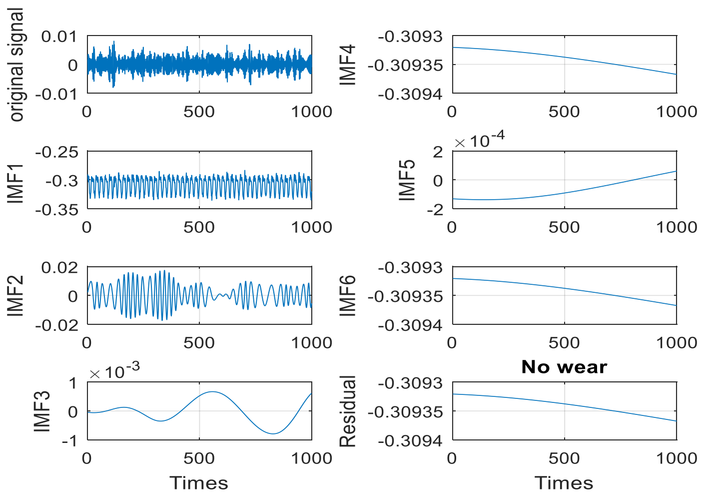

Fig. 7. IMFs in No wear

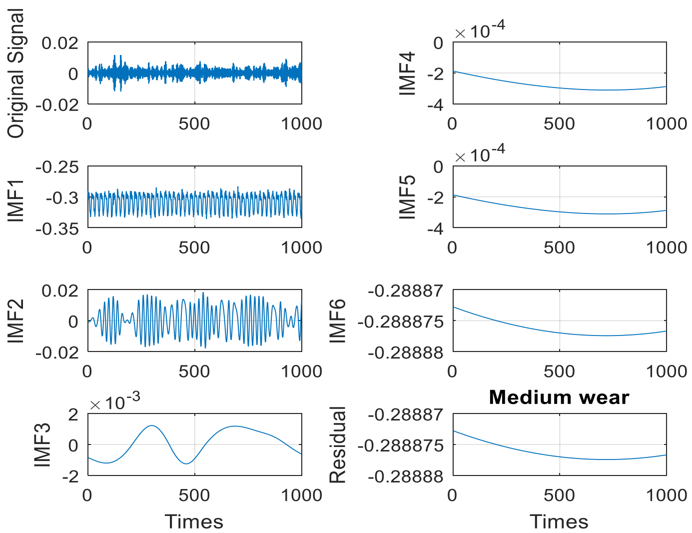

Fig. 8. IMFs in Medium wear

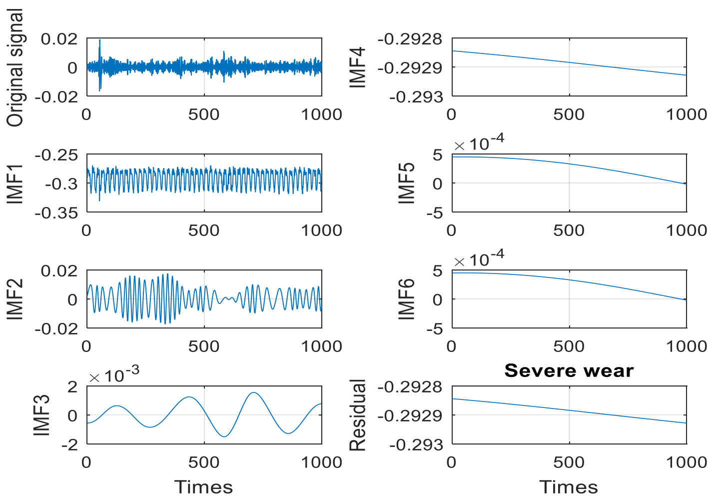

Fig. 9. IMFs in Sever wear

4.2 Interpretation Of Results

In the three figures presented above, we make a comparison between the EMD of new state, low wear and advanced wear and the IMFs decomposition in each stage.

Table 1. State values of the tool with MFIs

	New tool state	Low wear state	Advanced wear state
IMF1	**0.008471**	**0.01731**	**0.01886**
IMF2	**0.01802**	**0.02**	**0.01802**
IMF3	**0.001127**	**0.00162**	**0.001873**
IMF4	**-0.3085**	**0.0002957**	**-0.2924**
IMF5	**0.0004413**	**0.0002957**	**0.0007116**
IMF6	**-0.3085**	**-0.2886**	**0.0007116**
Résidu	**-0.3085**	**-0.2886**	**-0.2924**

We can conclude that despite the errors that occurred during the acquisition of the signals, we can say that this decomposition has allowed us to follow the evolution of our tool until its last stage (advanced wear).

4.3 Application Of Statistical Indicators The Imf3

The monitoring indicators of statistical type are calculated to see the influence of noise in the signal in order to detect defects. According to the results in table (1) the masking effect generated by the introduced noise decreases the indicator sensitivity, as shown by the Kurtosis and the Skewness.

On the other hand, the energy represented by the RMS value increases with the increase of the noise. Applying the EMD to the three indicators RMS, Kurtosis, Skewness of each mode, we have found that the kurtosis and skewness are very influenced by noise and for this reason, we observe this disturbance of values in the representation. They are unable to follow normally the evolution of the tool. But the RMS value is the only indicator that gives us more information.

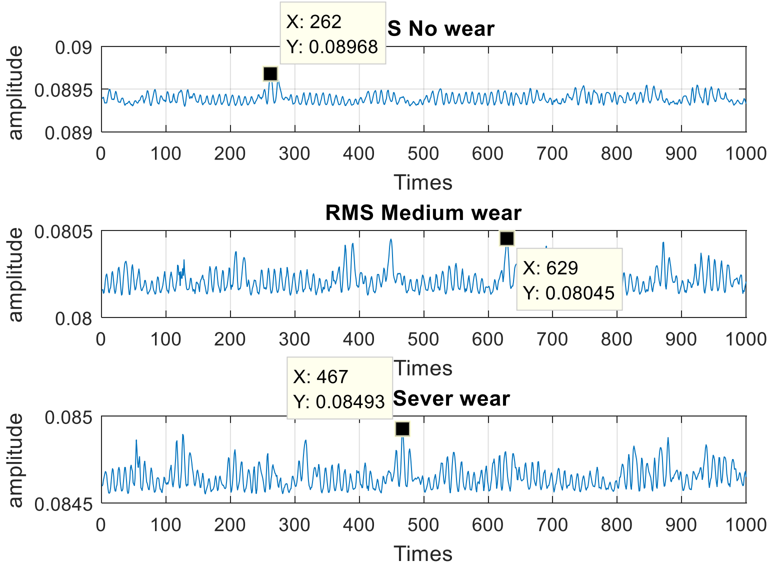

Fig. 10. RMS in the three phases of the No wear

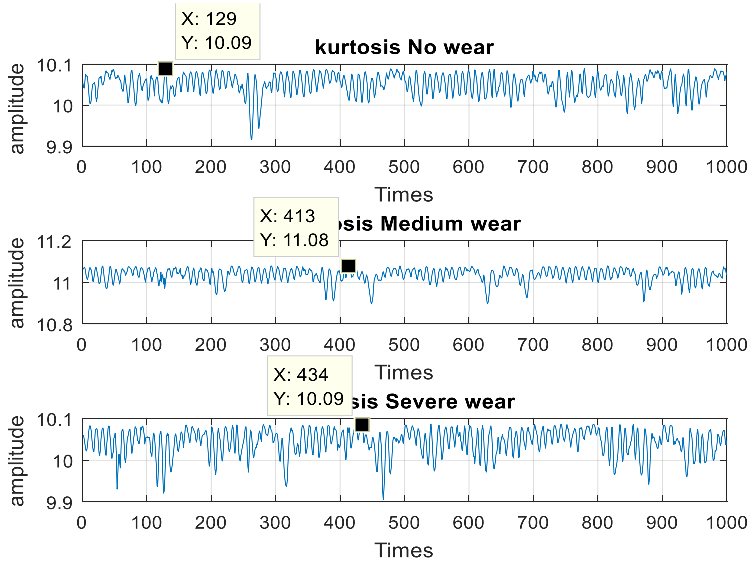

Fig. 11. Kurtosis in the three phases of Medium wear

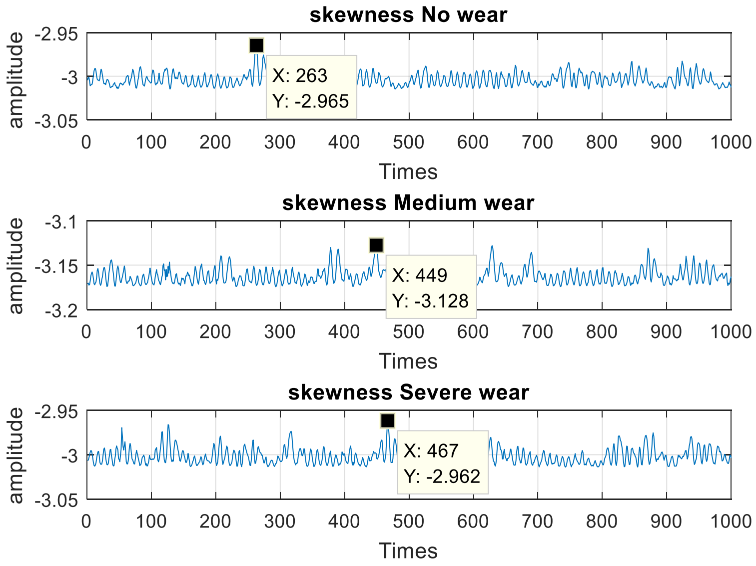

Fig. 12. Skewness in the three phases of Severe wear

Table 2. The values of the indicators applied to the MFI 3 with the 3 phases

Indicators	New tool	Low wear	Advanced wear
RMS	0.08975	0.08053	0.08504
KURTOSIS	10.09	11.08	10.09
SKEWNESS	-2.963	-3.112	-2.954

4.4 Application Of The Fourier Transform In The Original In The Three Stages

By applying the FFT function in the three (3) signals, the spectral analysis will allow us to highlight the different periodicities in the original signal. We have found that the wear evolution in the three phases is increasing with frequency and amplitude. This shows the degradation of the tool in the last stage (advanced wear) with 500 Hz of frequency and amplitude of 84.75. The original signals and their spectra are illustrated in the following figures to allow the differentiation of the signal with noise and its spectrum.

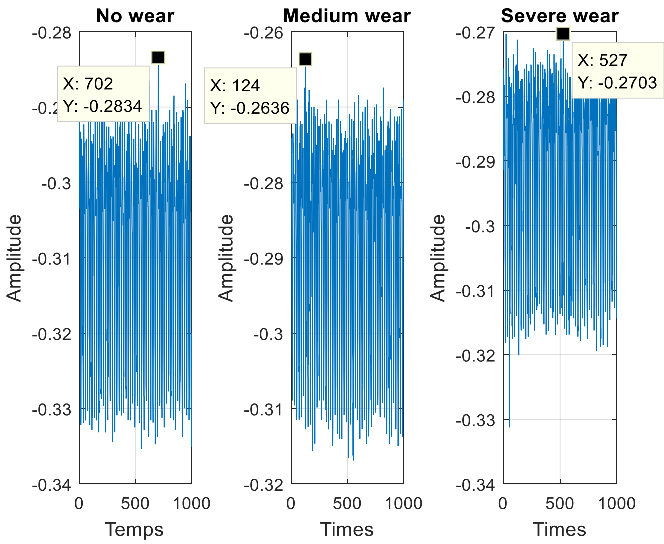

Fig. 13. Vibration signals three wear phases

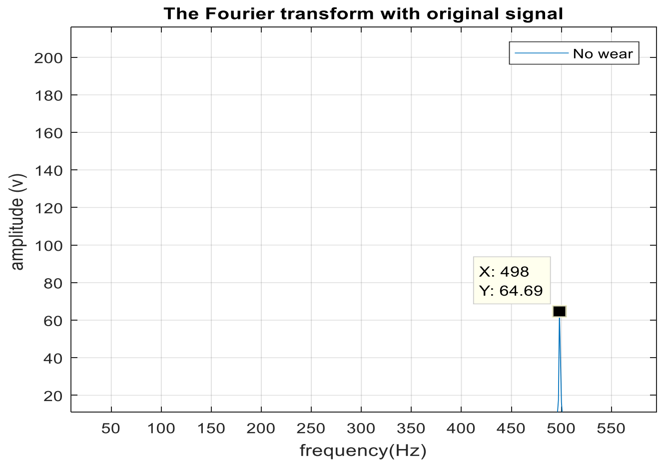

Fig. 14. Spectrum of the original signals No wear

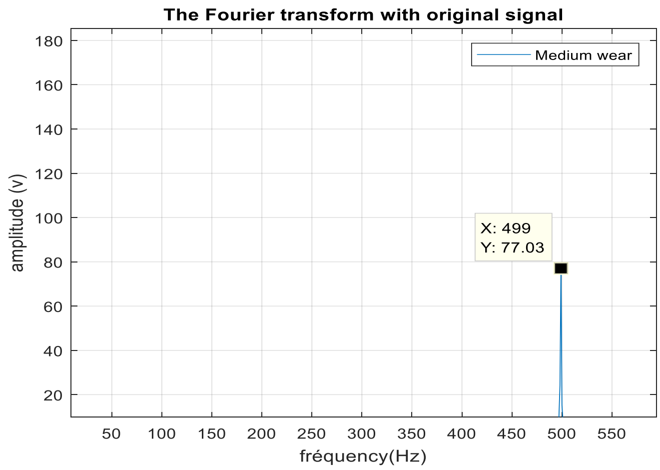

Fig. 15. Original signal of Medium wear

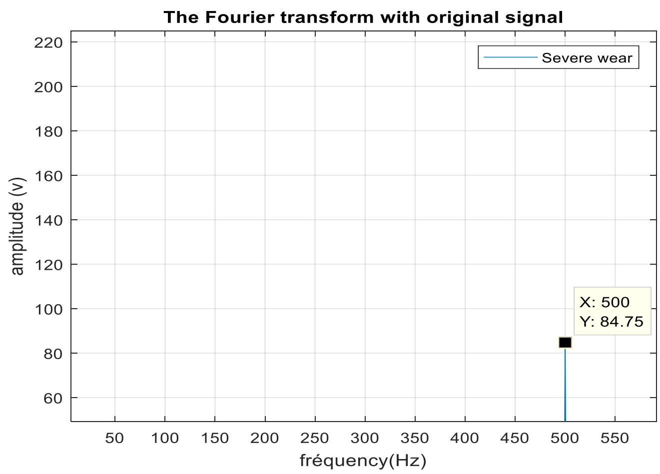

Fig. 16. Original signal Severe wear

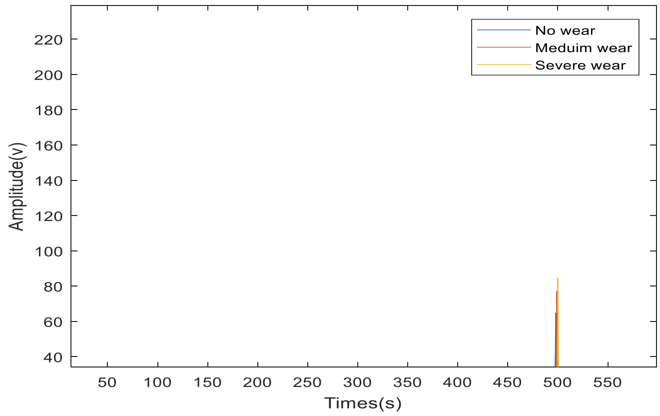

Fig. 17. Spectrum of three Sever wear

4.5 APPLICATION OF FFT FUNCTION IN THE IMF1 AND IMF3

To each MFI extracted in the original signal, we have chosen the IMF 1 and IMF 3 that are the informations carriers, we have applied the Fourier transform to have its spectrum. The reason of applying the Fourier transform allows us to locate and define the importance of the defect.

The figures below show the IMF signals and their spectra:

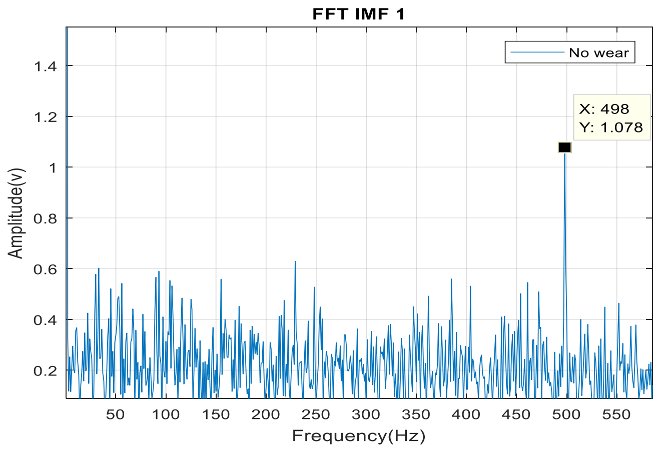

Fig. 18. Spectrum of IMF 1 No wear

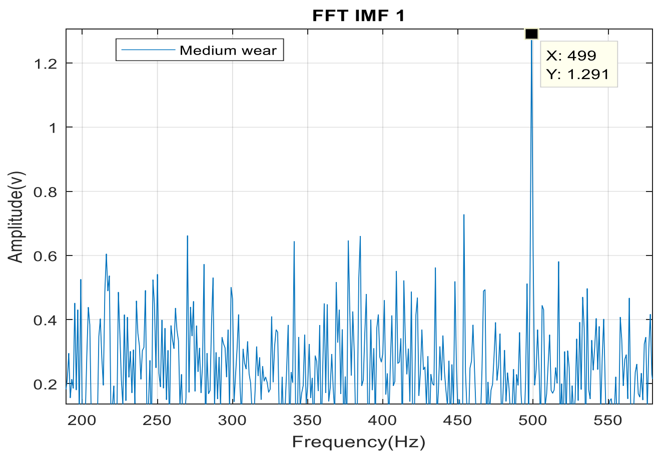

Fig. 19. Spectrum of IMF1 Medium

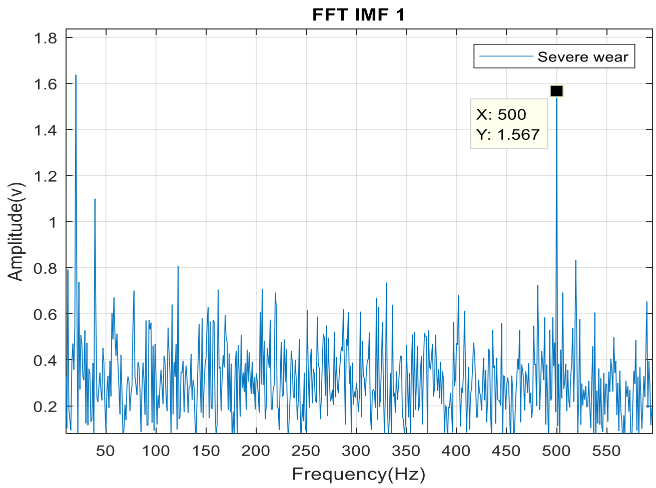

Fig. 20. Spectrum of MFI 1 Sever wear

We note that the three IMFs start with a high frequency after they decompose themselves in the low frequency; this leads us to say that the EMD is a decomposition from high frequency to low frequency with the presence of the supporting values.

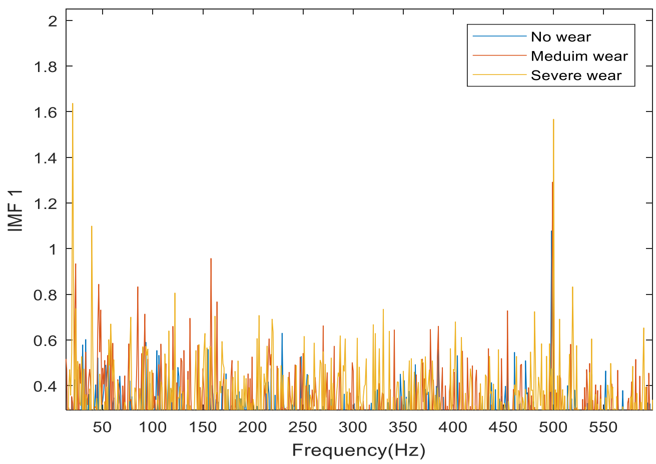

Fig. 21. the three tool wear spectra (IMF 1)

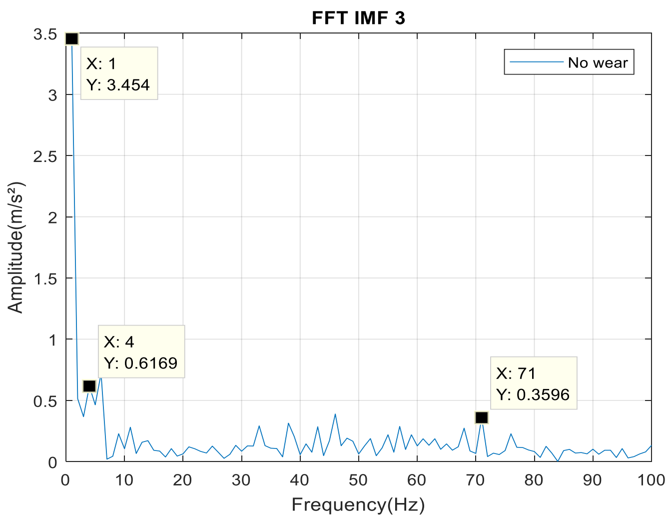

Fig. 22. Spectrum of IMF3No wear

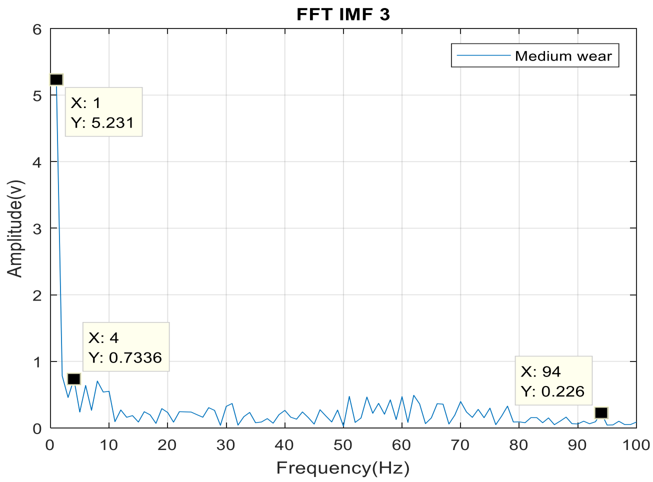

Fig. 23. Spectrum of IMF3Medium wear

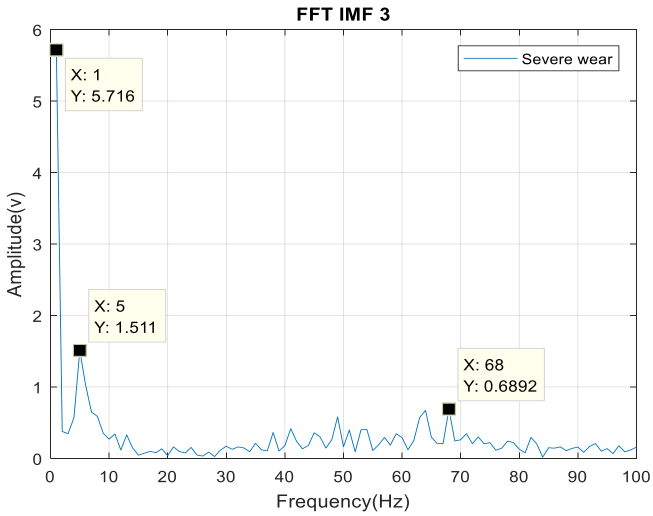

Fig. 24. Spectrum of MFI3Sever wear

4.6 Application Of The Fourie Transform In Indicators

In vibratory monitoring, statistical indicators are used as tools to detect defects. Several researches have successfully used these indicators, including the thesis of the Professor Bovic Kilundu and the work of the engineer Dany Katamba. We have used only three (3) indicators that follow: RMS, Kurtosis and Skewness. By applying the Fourier Transform in the three (3) indicators, we observe a rapid decay of the tool vibratory level in the three phases of wear up to the frequency range.

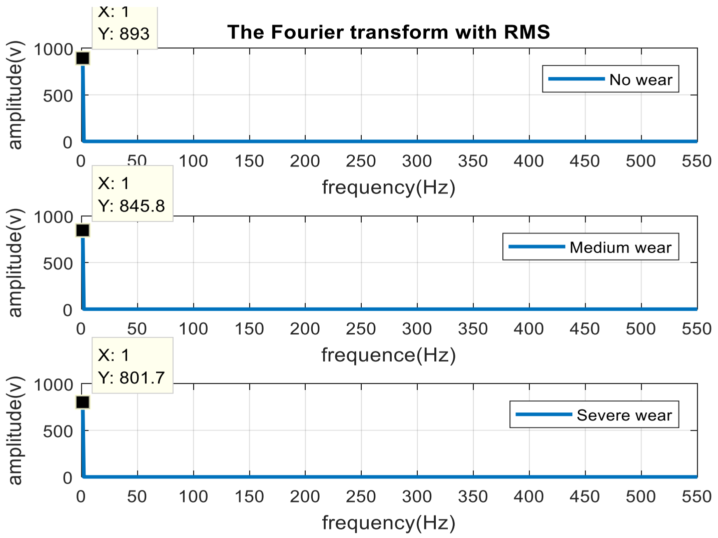

Fig. 25. FFT spectrum in RMS

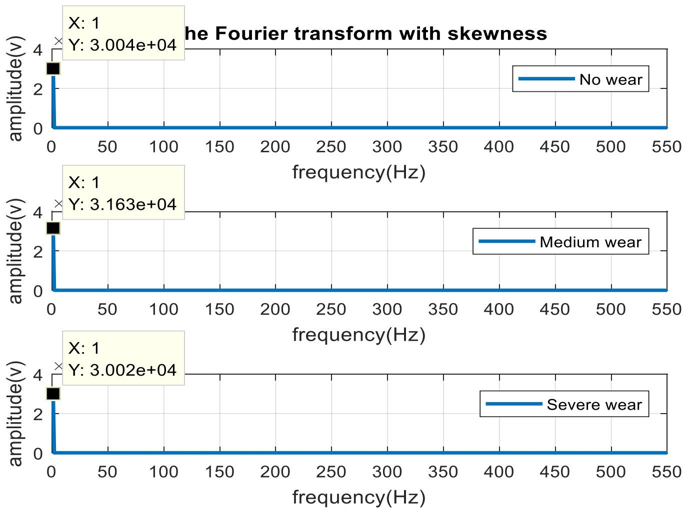

Fig. 26. FFT spectrum in Skewness

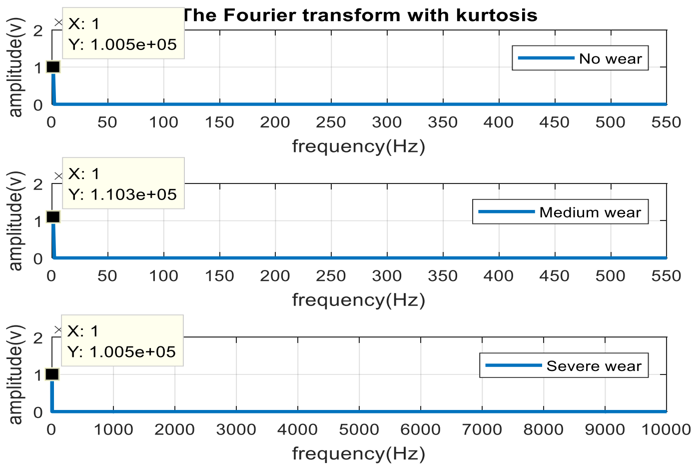

Fig. 27. FFT spectrum in Kurtosis

5 CONCLUSION

Today, studies show that vibration is a major issue in machining and one of the most limiting factors of reproductivity. In order to achieve an effective monitoring, we are interested in the monitoring of the cutting tool wear in turning with appropriate methods.

The temporal methods are more based on the statistical analysis of the collected signal, and allow to **f**ollow the evolution of a quantity derived from the power or the peak amplitude of the signal. In the case of our work, we have used only three indicators: RMS, KURTOSIS and SKEWNESS.

The frequency methods are based on the Fourier transform. The knowledge of the characteristic frequencies allows to identify and locate the defects coming from the mechanical components by analyzing their spectrum. They are used for complex machines with many mechanical components. On the other hand, in this case, it is necessary to look for techniques that allow us to get even closer to optimality, while trying to keep the advantages of wavelets.

Thus, we used the EMD method to concretize all the theories studied on monitoring based on the vibratory analysis and to process with the said method (EMD). A target and test procedures were set to make the acquisition of signals, then we have passed to the processing of signals under the software Matlab applying the EMD method in the vibratory signals, in order to bring out the MFIs. The results obtained can serve as good indicators for operators and for the production engineers that we are, in order to detect and predict the life of the cutting tools.

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