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FEATURE EXTRACTION AND FAULT DETECTION OF ROTATING MACHINERY BASED ON WAVELET PACKET TRANSFORM

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Abstract. Mechanical faults, such as mechanical looseness, rub, impact, crack, and others malfunctions, always make dynamic signals non-stationary. The vibration signals of rotating machinery are used to feature extraction and fault diagnosis, because they always carry the dynamic information of the machine. The key problem is how to extract useful features from vibration signals to fault detection. Conventional techniques, such as spectral and time series analysis, are effective tools to feature extraction for a broad range of faults in machines. However, they have difficulties with certain applications whose behavior is non-stationary and transient nature. In the present study, a rotor system model capable of describing the theoretical dynamic behavior resulting from shaft misaligned and unbalanced rotor is developed during run-up motion. A comparison between experimental and numerical results clearly indicates that validity of the theoretical model was successfully verified for fault misalignment. On the other hand, a new efficient feature extraction method based on the Wavelet Packet Transform (WPT) through energy retained in independent frequency bands is presented. Each packet provides information about a frequency band. The objective of the proposed method is to relate the packets containing most energy, calculated by Shannon entropy formula, to defect frequency and isolate the information in frequency range necessary to fault characterization. The applications of Wavelet Packet Transform using real and numerical data, as well as its theoretical and practical aspects of implementation are discussed. Finally, results show that the sensitivity and efficiency of the proposed method, using transient response during run-up, can be used successfully with alternative technique of fault detection in rotating machinery.

***Keywords**: Feature Extraction, Fault Detection, Wavelet Packet, Machine Run-up, Transient response.*

1. Introduction

Several programs of predictive maintenance and fault diagnostic systems use the machine condition to identify and classify faults through vibration analysis (Zhang et al., 1996). The vibration analysis has been extensively used in the diagnostic of faults and condition monitoring of rotating machinery and is make, in general, in the time domain or frequency domain.

Mechanical faults, such as mechanical looseness, rub, impact, crack, and others malfunctions, always make dynamic signals non-stationary. The vibration signals of rotating machinery are used to feature extraction and fault diagnosis, because they always carry the dynamic information of the machine. The key problem is how to extract useful features from vibration signals to fault detection. Conventional techniques, such as spectral and time series analysis, are effective tools to feature extraction for a broad range of faults in machines. However, they have difficulties with certain applications whose behavior is non-stationary and transient nature. To stationary signals, the spectral analysis or Fourier Transform (FT) is extremely useful. However, it is not suitable to signal analysis whose behavior is of non-stationary or transient nature.

The transient response obtained during run-up and shut-down is of non-stationary nature. To deal with non-stationary signals, several time-frequency (Gabor Transform, Wigner-Ville, etc.) and time-scale (Wavelet Transform) techniques analysis were developed. The Wavelet Transform is an effective tool for stationary and non-stationary signal processing. The WT let to provide information contained in the signal in time and frequency domain simultaneously.

The vibrations signals of rotating machinery are, mainly, caused by unbalance, misalignment, mechanical looseness, rub, cracks, and so on. The majority of the studies available in the literature have paid attention to diagnostic on these faults by analysing the steady state vibrations (Wauer, 1990; Xu and Marangoni, 1994; Sekhar and Prabhu, 1995 and Hamzaqui et all, 1998). On the other hand, the dynamic behavior study of rotors and the diagnostic of faults using transient response during run-up, and shut-down of a machine have woken up a lot of interest on researchers (Smalley, 1989; Gasch, 1993; Pacheco & Steffen Jr., 1995, Al-Bedoor, 2000; Santiago & Pederiva, 2003).

In the present study, a rotor system model capable of describing the theoretical dynamic behavior resulting from shaft misaligned and unbalanced rotor is developed during run-up motion. A comparison between experimental and numerical results clearly indicates that validity of the theoretical model was successfully verified for fault misalignment. On the other hand, a new efficient feature extraction method based on the Wavelet Packet Transform (WPT) through energy retained in independent frequency bands is presented. Each packet provides information about a frequency band.

The objective of the proposed method is to relate the packets containing most energy, calculated by Shannon entropy formula, to defect frequency and isolate the information in frequency range necessary to fault characterization. The applications of Wavelet Packet Transform using real and numerical data, as well as its theoretical and practical aspects of implementation are discussed. Finally, results show that the sensitivity and efficiency of the proposed method, using transient response during run-up, can be used successfully with alternative technique of fault detection in rotating machinery.

2. Wavelet Transform

The Continuous Wavelet Transform (CWT) of signal $x(t)$ is defined as:

$$CWT(a,b) = \int_{-\infty}^{+\infty} x(t).\psi^*_{a,b}(t)\, dt\,, \quad a \ e \ b \in \Re\,, a \neq 0 \tag{1}$$

where $\psi(t)$ is the mother wavelet, $\psi^*(t)$ is the complex conjugate of $\psi(t)$ and $\psi_{a,b}(t) = 1\big/\sqrt{|a|}\ \psi\big((t-b)/a\big)$ are the daughter wavelets. Here $a \succ 0$ is the scaling parameter and b is the translation or time shifting parameter. The difference between Short-Time Fourier Transform (STFT) and the CWT is that in the CWT use the variable scale a instead of variable frequency f in the STFT (Misiti *et al*, 1997; Mallat, 1989).

In the calculus of CWT the parameters a and b change continuously. However, the calculating coefficients of wavelet at every possible scale can represent a fair amount of computational work and it generates an awful lot of data. Therefore, the utilization of Discrete Wavelet Transform (DWT) become important, as it let the discretization of wavelet based on powers of two, or 2^j scale, called dyadic scale.

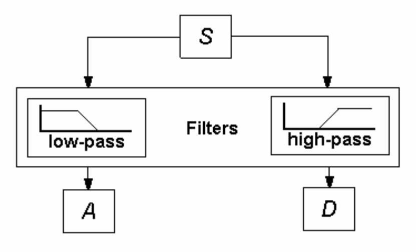
The utilization these scale become the computational implementation fast and the data analysis more efficient. As, the parameters a and b of expression (1) are substituted as 2^j and $k2^j$, respectively, and the DWT is defined as (Chui, 1992):

$$DWT(j,k) = \int_{-\infty}^{+\infty} x(t).\psi^*_{j,k}(t)\, dt\,, \quad j \ e \ k \in \mathrm{Z}\ , \tag{2}$$

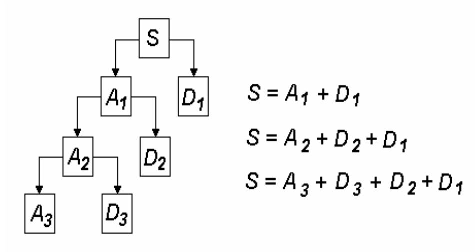
where, $\psi_{j,k}(t) = 1\big/\sqrt{2^j}\ \psi\big((t-k2^j)/2^j\big)$ are the wavelet functions orthogonal (Daubechies, 1988).

Similar the Fast Fourier Transform (FFT), there is an algorithm to implementation of DWT based on decomposition Fast of Wavelet Transform (FWT), which is normally used, and is called Mallat algorithm, which was developed by Mallat in 1988 (Misiti *et al*, 1997; Mallat, 1989). This algorithm use a filtering process to decompose the signal, where the content of signal of low frequency is called of approximation, and the high frequency is called of detail. This filtering process use the special filtering process to decompose the signal in approximations and details, and can be interpreted with low-pass and high-pass filters, respectively, as showed in Fig. 1(a).

The multiresolution theory let to decompose the signal: first, the discrete signal original S is decomposed in the first level in two components A_1 and D_1 by a low-pass filter and a high-pass, respectively. The A_1, is called of approximation of signal and D_1, is called of detail of signal. In the second level, the approximation A_1 is now decomposed in a new approximation, A_2, and a detail D_2. This procedure can be repeated to third level, fourth, and so on. The Fig. 1(b) shows the wavelet decomposition tree of the signal in three levels.



(a)

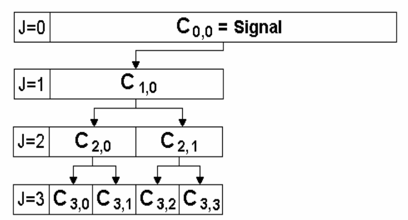


(b)

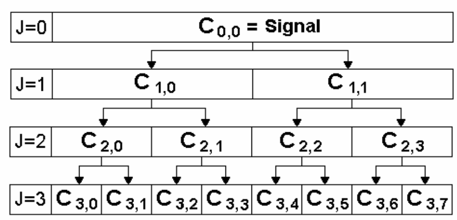
Figure 1. (a) Diagram multiresolution analysis, (b) Wavelet decomposition tree in three levels.

On other hand, the Wavelet Packet Transform (WPT) is a generalization of discrete wavelet transform. While the DWT showed in the Fig. 2(a) decompose only the signal in low frequencies, the WPT showed in the Fig. 2(b) decompose the signal in low and high frequencies. Each vector A_j has $N_t / 2^j$ coefficients, where N_t is the length of the signal S, and provides information about a frequency band $[0, F_s / 2^{j+1}]$, where F_s is the sampling frequency of the signal. Each node or packet of WPT is indexed with a pair of integers (j, k), where j is the corresponding level of decomposition and k is the order of the node position in the specific level. In each level j, there is 2^j nodes and their order is $k = 0,1,...,2^j - 1$. For example, in the third level ($j = 3$), there are eight nodes or packets. A vector of wavelet packet coefficients $c_{j,k}$ corresponds to each node (j,k). The length of a vector $c_{j,k}$ is approximately $N_t / 2^j$.

In the Fig. 2(b), the vectors $c_{j,k}$ retain information of original signal in different frequency bands. For example, if the sampling frequency of signal is 16000 Hz, then the analysis frequency band related to vector $c_{0,0}$ is of 0-8000 Hz. To $c_{1,0}$ is 0-4000 Hz, to $c_{1,1}$ is 4000-8000 Hz, to $c_{3,0}$ is 0-1000 Hz, and so on. An advantage of WPT is that it let to analyze the information contained in the signal (stationary and transient) in different time-frequency resolution. Another advantage of WPT in despite of the data compacting of information contained in the signal. For example, to $j = 3$ and $N_t = 1024$ samples, the vector $c_{3,0}$ has $N_t / 2^j = 128$ samples and frequency band equal to 0-1000 Hz.



(a)



(b)

Figure 2. Decomposition of original signal with (a) DWT e (b) Wavelet Packet.

It is observed that each packet $c_{j,k}$ of WPT retain compact information of original signal. This fact is very important in the analysis and signal processing, mainly in the field of diagnostic of faults, as can retain information of signal only in that frequency band where the frequencies of fault appearing. In practice, normally choose the packets that retain more information of signal original and rule out the packets that contain noise and information not very much important. For this, several criteria has been used to selection of the excellent packets. A criterion enough used is that based on quantizing of energy contained in the signal (Scheffer & Heyns, 2001). In this work, the Shannon entropy formula is used to quantize the energy contained in the signal and in each node of wavelet packet (Misiti *et al.*, 1997), which is defined by:

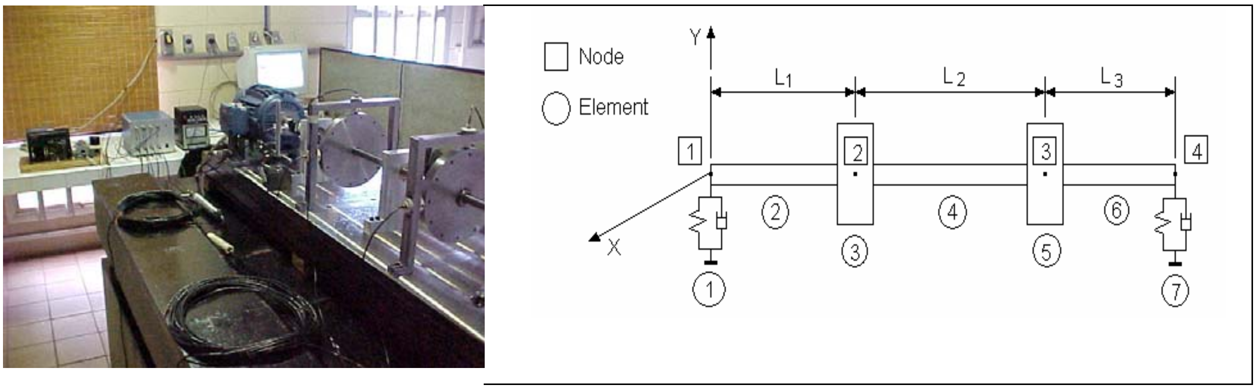
$$E(s) = -\sum_i s_i^2 \log(s_i)^2 \qquad (3)$$

where s is the signal and s_i is the sample of the signal in instant i. Therefore, the application of wavelet packet transform based on quantizing of energy contained in the signal in independent frequency bands let the extraction and obtaining of information enough compact. This can be very important in tasks of pattern recognition using neural networks (Santiago, 2004).

3. Transient response

In the present study, a rotor system model capable of describing the dynamic behavior resulting from shaft misaligned and unbalanced rotor is developed during start-up motion. It is now more and more important to know what happens when a rotor starts-up, stops or goes through a critical speed, effects known as transient motions.

The experimental set-up is illustrated in Fig. 3(a). It consists an electrical motor, a flexible coupling and two disks mounted on the rotating shaft supported by two identical ball bearings.



(a) (b)

Figure 3 - (a) Details and instrumentation used in experimental set-up and (b) Rotor system model.

In this modeling, Finite Element Method (FEM) is preferred. Figure 3(b) present the rotor systems model of discretization containing 7 finite elements (1, 7 - Bearing elements; 2, 4, 6 - Shaft elements and 3, 5 - Disks elements). The shaft was modeled as three finite element beams with a constant circular cross-section. The finite element used has two nodes, including four displacements and four slopes. Combining the effect of shaft, bearings and disks element models, and including all degrees of freedom of the rotor systems, the general differential equation of transient motion can be written as:

$$[M]\ddot{q}(t)+[C1+\dot{\phi}C2]\dot{q}(t)+[K1+\ddot{\phi}K2]\,q(t)=F(t) \tag{4}$$

where $[M]$ is the classical mass matrix and includes the influence of the secondary effect of rotatory inertia of the shaft, mass and diametral moments of the disk. The matrices $[C1]$ and $[C2]$ gives the bearings damping and gyroscopic effect, respectively. The matrices $[K1]$ and $[K2]$ includes the bearings stiffness and stiffness of the shaft elements, respectively. More details about the individual matrices of Eq. (4) are given in (Lalanne and Ferraris, 1998). The $q(t)$ is the vector of generalized co-ordinates containing all the nodal displacements and $F(t)$ is the vector of excitation forces used to model the faults, such as unbalance forces and misalignment forces. Depending on the type of faults, the vector $F(t)$ changes.

To investigate the effects of misalignment on the rotor dynamic characteristics is considered a dynamic model for coupling angular misalignment (where the shafts centerlines of the two shafts meet at an angle) and parallel misalignment (the shafts centerlines are parallel but displaced from one another).

In this study, the reaction forces and moments of shaft developed due to angular and parallel misalignment given in (Sekhar and Prabhu, 1995; Lee and Lee, 1999) have been used in the numerical analysis. Several references (Xu and Marangoni, 1994; Sekhar and Prabhu, 1995; Lee and Lee, 1999) showed that an increase in angular and parallel misalignment had caused increase in the second harmonic of the radial vibration response. Then, the misalignment forces are assumed in this work to be periodic at the twice the rotational frequency of the shaft and the unbalance forces is equal a rotational frequency or fundamental frequency. Therefore, the reaction forces due to shaft misalignment and unbalance rotors are then incorporated into the excitation force $F(t)$ in the Eq. (4) of transient motion at the corresponding degrees of freedom.

Table 1. Parameters used in the experimental and numerical analysis

Shaft	
Diameter, D	$17\text{x}10^{-3}$ m
Length, L_1, L_2, L_3	$180\text{x}10^{-3}$ m, $360\text{x}10^{-3}$ m, $180\text{x}10^{-3}$ m
Bearings	
Stiffness, $Kxx1 = Kyy1$	$5.64\text{x}10^{5}$ N/m
Stiffness, $Kxx2 = Kyy2$	$9.95\text{x}10^{5}$ N/m
Damping, $Cxx1 = Cyy1$	43.6 Ns/m
Damping, $Cxx2 = Cyy2$	5.37 Ns/m
Disks	
Mass, m	4 kg
Polar moment of inertia, I_p	0.0162 kg m^2
Unbalance eccentricity, m_u	$2\text{x}10^{-4}$ Kg
Inbalance eccentricity, e	$80\text{x}10^{-3}$ m

4. Numerical analysis

The transient response due to excitation forces that characterize faults such as misalignment and unbalance is obtained by integrating of Eq. (4), using the Runge-Kutta integration method. In this analysis the characteristics of the bearings will be assumed to be constant and the angular velocity is not constant and is a function of time. The rotor systems model data used in the numerical analysis are given in Tab. (1). The analysis has been carried out considering the effect of angular misalignment forces actuating in the first bearing (near electrical motor) and the effect of unbalance forces actuating in the two disks, both in the x direction axis (horizontal) and y direction axis (vertical) as showed in Fig. 4(b). Two levels of misalignment effect were simulated considering theoretical values of steel plates of 1 mm and 2 mm of thickness inserted in the base of first bearing. Figure 4(a) and 4(b) shows time run-up of unbalance rotor obtained for first and second disk in y direction, respectively. The transient response shows that the rotor passing by the first and second critical speed with an acceleration of 20 rad/s^2 .

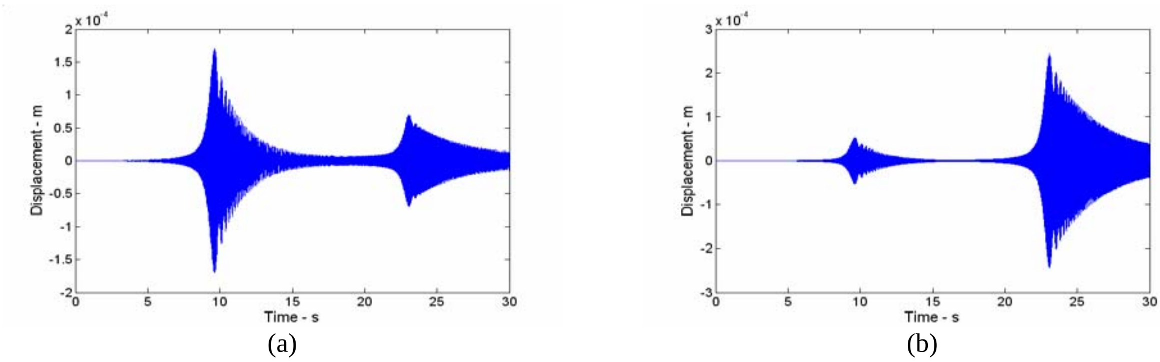


Figure 4 - Transient response of unbalanced rotor during 30 s, (a) Disk 1 and (b) Disk 2.

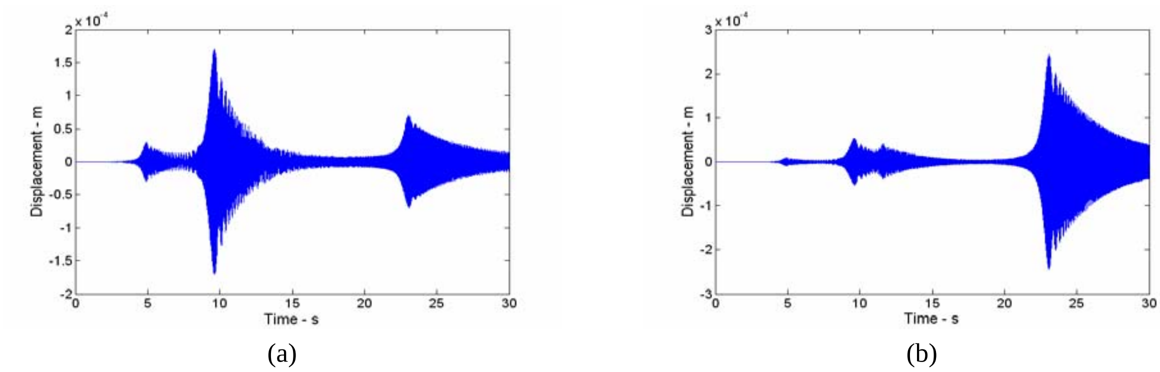
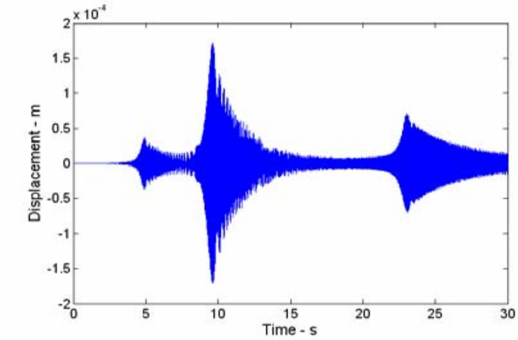
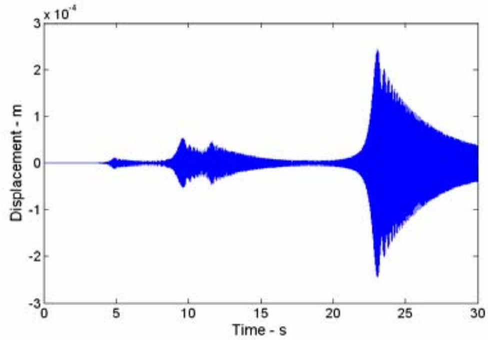


Figure 5 - Transient response for fault misalignment of 1 mm during 30 s, (a) Disk 1 and (b) Disk 2.

Figures 5(a) and 5(b) show the time run-up for misalignment fault of 1 mm in the first and the second disk, respectively. It can be seen that the effect of the second harmonic due to angular misalignment fault included in the theoretical model has excited the first and the second critical speed. The effect of misalignment in the second critical speed appears clearly evident in the transient response in the second disk, Fig. 5(b), when compared with the transient response in the first disk, Fig. 5(a). Similarly, Figs 6(a) and 6(b) show the time run-up for misalignment fault of 2 mm in the first and the second disk, respectively. These figures show that the transient response of rotor was obtained in the first and second disk in y direction. From the practical point of view, the vibration signals analysis during machine run-up and shut-down is very important in the field of condition monitoring and fault diagnostic, in despite the early detection of faults before breakdown of a machine.



(a)



(b)

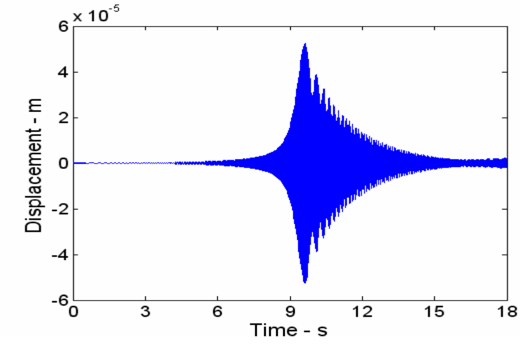
Figure 6 - Transient response for fault misalignment of 2 mm during 30 s, (a) Disk 1 and (b) Disk 2.

In this part, the Wavelet Packet Transform (WPT) is applicable to analysis of transient signals, using simulated signals. The objective this study is show the possibility of application of WPT with an alternative technique of extraction and compacting of parameters, aiming the diagnostic of faults in rotating machinery. For this, it is used simulated transient response obtained in the second disk and in y direction due to unbalance fault, misalignment fault of 1 mm and misalignment fault of 2 mm, shown in Figs 7(a), 8(a) and 9(a), respectively.

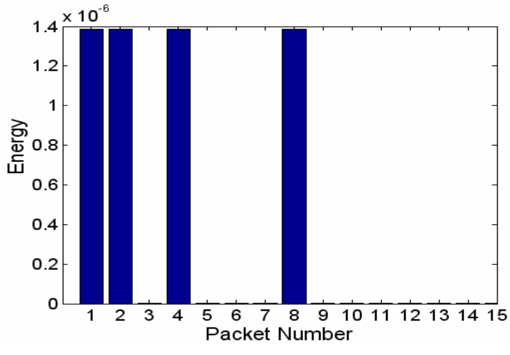
During the phases of simulation and application of WPT in transient signals shown in Figs. 7(a), 8(a) and 9(a), were used 18000 samples, acquisition time of 18 seconds, sampling frequency of 1000Hz and wavelet db10 of Daubechies dbN family (Misiti et al., 1997).

The Figs 7(b), 8(b) and 9(b) show the energy distribution contained in the compacted signal by expression (3) in function of number packets or of independent frequency bands. To unbalance condition, the Fig. 7(b) show a global representation of distribution energy retained in independent frequency bands, according to WPT diagram shown in Fig. 2(b). It can be seen in Figure 7(b) the presence of energy values appearing retained only in 1, 2, 4 and 8 nodes, as related to transient response due to unbalance during passage by the first critical speed.

To fault misalignment of 1 mm showed in Fig. 8(b) appear a slight increase of energy retained in 1, 2, 4 and 8 nodes, due to misalignment fault of 1 mm, included in the theoretical model, excite the first critical speed. In this fault condition is important to observe the appearing of energy value retained in 9 node, which is related to excitation with second critical speed.

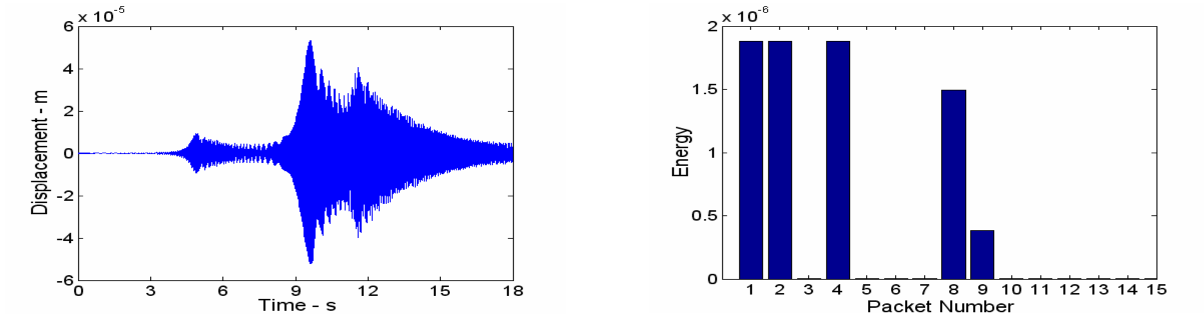


(a)



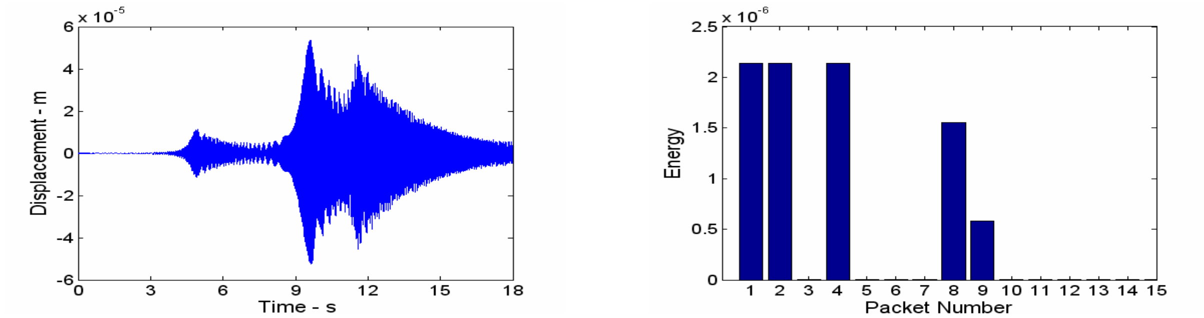
(b)

Figure 7 - (a) Transient response due to unbalance fault, (b) WPT Energy



(a) (b)

Figure 8 - (a) Transient response due to misalignment fault of 1 mm, (b) WPT Energy



(a) (b)

Figure 9 - (a) Transient response due to misalignment fault of 2 mm, (b) WPT Energy

Similarly, to fault misalignment of 2 mm showed in Figure 9(b) observes again an increase of values of energy retained in 1, 2, 4, 8 and 9 nodes when the misalignment level increased of 1 mm to 2 mm. This difference is more evidenced observing only the value of energy contained in 9 node, which is related to excitation of second critical speed due to misalignment effect, when compared with conditions of misalignment fault of 1 mm, Fig. 8(b), and unbalance fault, Fig. 7(b). The results obtained with application of WPT are very important, mainly, in the monitoring and diagnostic of faults, as the effect of evolution of a fault can be monitored, as well as differentiate a fault of another though of quantizing of energy contained in the signal in independent frequency bands. An advantage of WPT is let the extraction and obtaining of information contained in the signal enough compact. It is important observe that the data extraction and compacting are valid to stationary and transient signals (Santiago, 2004).

5. Experimental analysis

In this part, the wavelet analysis is applicable to the experimental signals obtained for different fault conditions using the vibration signals during machine run-up. The faults conditions inserted in the experimental set-up, showed in Fig. 3, are normal condition (unbalanced rotor), two levels of misalignment and mechanical looseness. The rotor shaft is driven by an electrical motor (three-phase asynchronous motor 220-380 V, power 3 CV). An inverter frequency (Newtronic FUJI FVR-E7S-EX) is used to vary the rotating speed continuously increasing or decreasing from 0 to 2400 rpm (40 Hz). The instrumentation used in the experiment includes three non-contacting displacement transducers or proximity probes used for displacement measurements. The three probes measure directly the rotor displacement in the horizontal and vertical directions. The third displacement probe, mounted in the vicinity of the motor's output shaft, was used as a tachometer signal to control the motor angular speed and acceleration. Two levels of misalignment fault (0.5 mm and 1 mm) were introduced in the first bearing by inserting steel plates of 0.5 mm and 1 mm of thickness, respectively, in the bearing base. The mechanical looseness was inserted by loose of four bolts at the first bearing base. Other real parameters used in the experimental analysis are given in Tab. (1). In all signals vibration acquisition during machine run-up was used 12000 points of sampling, sampling frequency of 1000Hz and rotating speed varying from 0 to 2400 rpm. The measuring device was based on a Pentium II/300 MHz computer, equipped with a PCMCIA DAQCard-1200 data acquisition card from National Instruments. This is an 8-channel software-configurable 12-bit data acquisition card, with a total sampling rate capacity of 100 KHz. The code of the algorithm that was used in the data acquisition procedure has been developed under the *LabVIEW* programming environment of National Instruments.

In this work, the WPT is applicable in the transient response, which went obtained during the machine run-up and shut-down, aiming the diagnostic of faults in rotating machinery. The transient response during run-up to normal condition or without fault was obtained to do comparison with conditions with faults. The objective of the proposed method is to relate the packets containing most energy, calculated by Shannon entropy formula, to defect frequency and isolate the information in frequency range necessary to fault characterization using the transient response.

The next, the Fig. 10 show the displacement signals (four patterns) obtained to different conditions of faults inserted in the experimental set-up (normal condition, misalignment fault of 0.5 mm, misalignment fault of 1 mm and mechanical looseness). The acquisition of vibration signals during machine run-up was used 12000 points of sampling, sampling frequency of 1000Hz and rotor acceleration of $a = 20\ rad/s^2$. The Shannon entropy formula, expression (3), is used to quantize the energy contained in the transient signal in each frequency band of wavelet packet. Several important aspects observed in this study motivated the application of WPT to fault diagnostic in rotating machinery such as: 1) Tendency of uniformity of energy values and repeatability of four patterns of faults, showed in Fig. 11(a) to ten first acquisitions; 2) Decreasing of quantized energy values simultaneously in each packet or frequency band to three patterns of faults according to acceleration increase, showed in Fig. 11(b), 11(c) and 11(d).

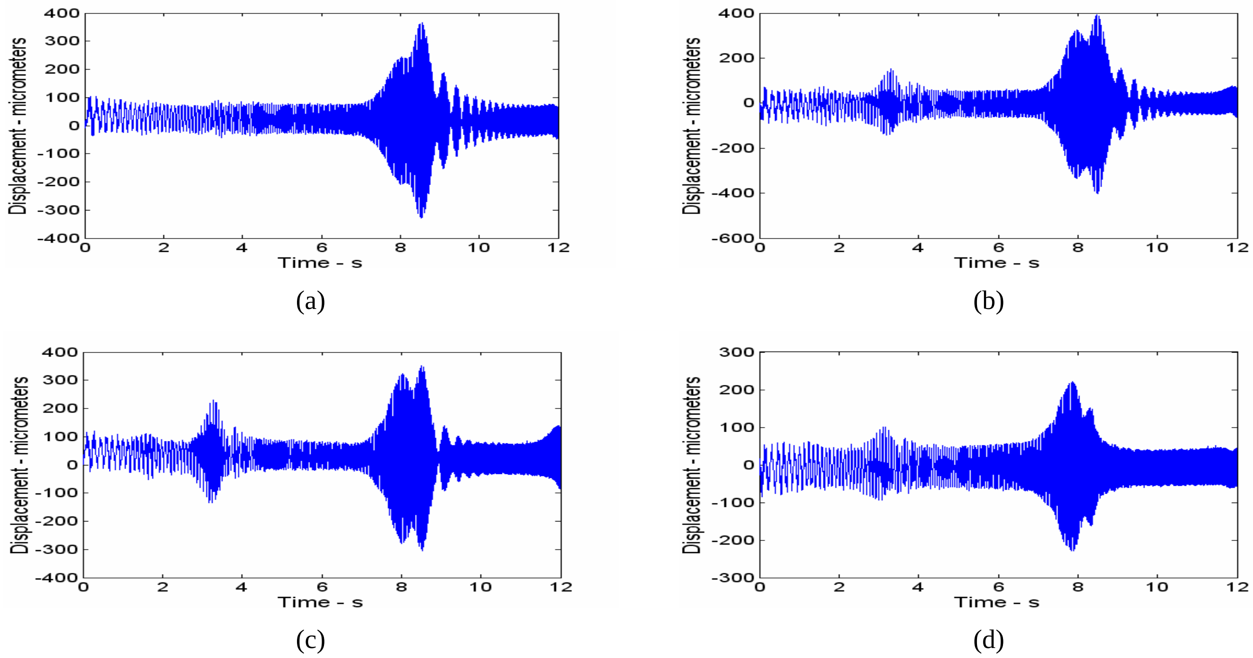


Figure 10 -(a) Normal condition, (b) Misalignment of 0.5 mm, (c) Misalignment of 1 mm and (d) Mechanical looseness.

Another condition enough suitable to become the diagnostic of faults more efficient is using a value of sampling frequency lower. The Fig. 12 show the energy distribution obtained though WPT in function of node numbers or frequency bands using the sampling frequency equal to 380 Hz. In this case, the transient response (run-up) were acquired to same faults with 4900 points of sampling, rotating speed varying from 0 to 2400 rpm and rotor acceleration of $a = 20\ rad/s^2$.

To normal condition, showed in Fig. 12(a) observes the presence of energy values retained in 1, 2, 4, 8 and 9 nodes. To misalignment fault of 0.5 mm showed in Fig. 12(b) appear a slight increase of energy retained in 1, 2, 4 and 8 nodes, due to misalignment fault of 0.5 mm excite the first critical speed. In this fault condition is important to observe an increase of energy value retained in 9 node, which is related to excitation with second critical speed. Similarly, to misalignment fault of 1 mm showed in Fig. 12(c) observes again an increase of energy values retained in 1, 2, 4, 8 and 9 nodes when the misalignment level increased of 0.5 mm to 1 mm. This difference is more evidenced observing only the value of energy contained in 9 nodes, which is related to excitation of second critical speed due to misalignment effect, when compared with conditions of misalignment fault of 0.5 mm, Fig. 12(b), and normal condition, Fig. 12(a). In the case of mechanical looseness showed in Fig. 12(d) observes that all energy values retained in 1, 2, 4, 8 e 9 nodes are lower than the energy values to another faults. Then, when another frequency band is excited this increases the differentiation of fault patterns and consequently improves the efficiency of diagnostic of faults though WPT. The results show that the sensitivity and efficiency of the proposed method, using transient response during run-up and WPT, can be used successfully with alternative technique of fault detection in rotating machinery.

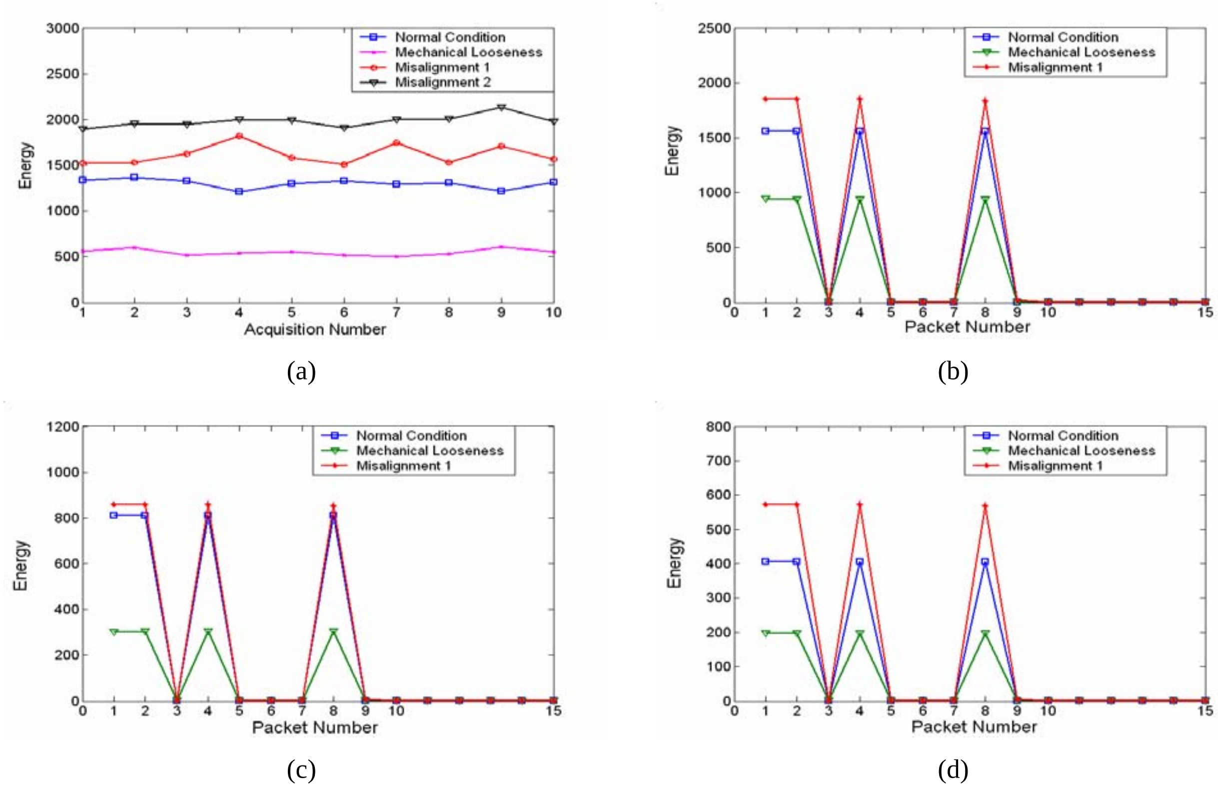


Figure 11 - (a) Energy of tem first acquisitions, (b) Energy to $a = 20\ rad/s^2$,

(c) Energy to $a = 38\ rad/s^2$ e (d) Energy to $a = 75\ rad/s^2$.

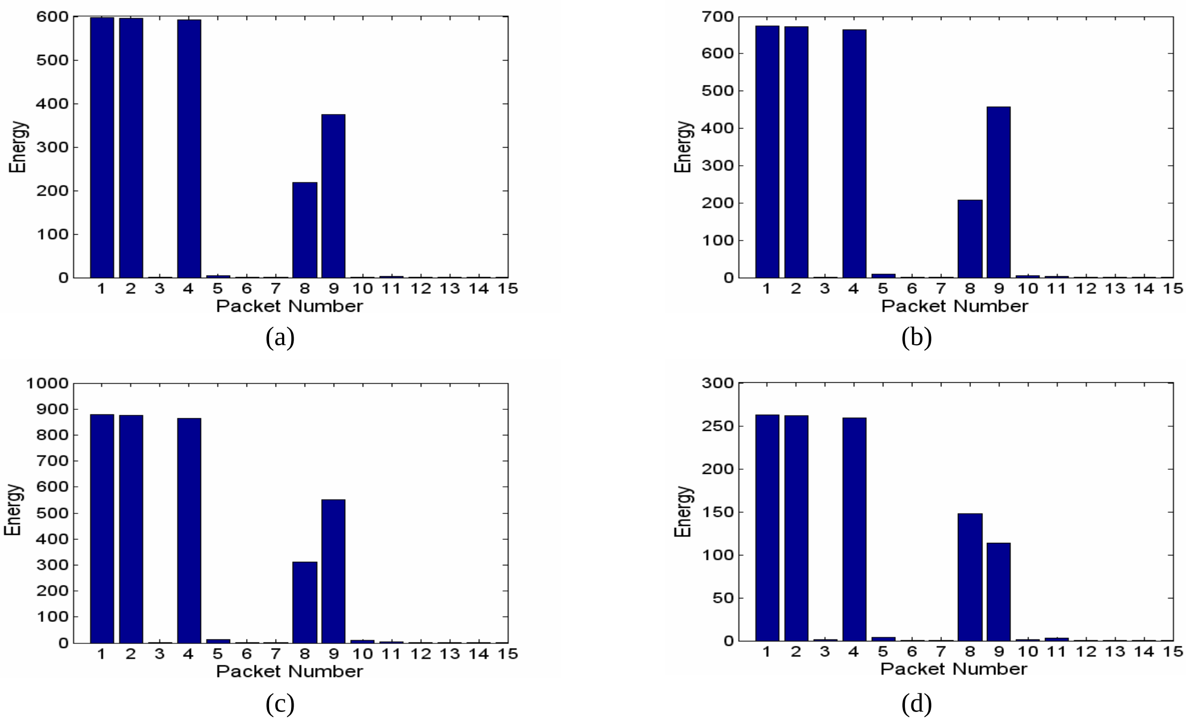


Figure 12 - Energy Distribution of WPT to, (a) Normal Condition, (b) Misalignment 1,
(c) Misalignment 2 and (c) Mechanical Looseness.

5. Conclusions

An advantage of Wavelet Packet Transform (WPT) is that it let to analyze the information contained in the signal (stationary and transient) in different time-frequency resolution. Another advantage of WPT in despite of the data compacting of information contained in the signal. This fact is very important in the analysis and signal processing, mainly in the field of diagnostic of faults, as can retain information of signal only in that frequency band where the frequencies of fault appearing. In practice, normally choose the packets that retain more information of signal original and rule out the packets that contain noise and information not very much important. This can be very important in tasks of pattern recognition using neural networks. In this study, a new efficient feature extraction method based on the Wavelet Packet Transform (WPT) through energy retained in independent frequency bands has been presented. Each packet provides information about a frequency band. The objective of the proposed method is relate to the packets containing most energy, calculated by Shannon entropy formula, to defect frequency and isolate the information in frequency range necessary to fault characterization. The applications of WPT using real and numerical data, as well as its theoretical and practical aspects of implementation were discussed. Finally, results show that the sensitivity and efficiency of the proposed method, using transient response during run-up, can be used successfully with alternative technique of fault detection in rotating machinery.

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