# Fault Diagnosis of Roller Bearings Using the Wavelet Transform

**Ioannis Tsiafis*, Konstantinos D. Bouzakis***
**Antonios Kaplanis**, Athanasios Karamanidis**, Thomas Xenos ****

**Mechanical Engineering Department, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece (Tel: 00302310 996034; e-mail: tsiafis@ eng.auth.gr).*

***Department of Electrical & Computer Engineering, Aristotle University of Thessaloniki Thessaloniki, Greece.*

Abstract: Ball bearings are perhaps the most widely used machine elements and a lot of important and expensive mechanic systems are based on them. Thus, it is necessary to establish a method to detect faults in order to keep the systems running properly. Fault identification of rolling element bearings employing condition monitoring techniques has been the subject of extensive research for the last two decades. Vibration signals of machines provide the dynamic information of the machine condition taking into account the fact that whenever the rolling element encounters a defect, a short duration impulse is generated. These signals are very useful for fault diagnosis. In this paper, the Fast Fourier Transform (FFT) is initially employed for an first comparison between healthy and defective bearings. Then, the main signal analysis is performed using the Wavelet Transform Method (WTM) which proves very effective in problems of this type.

*Keywords:* Bearings, Vibration, FFT, Wavelet.

## 1. INTRODUCTION

Impulses are generated due to the motion of rolling elements. It is well established that defects on bearings generate impulses observed as extra frequency components in a Fast Fourier Transform (FFT) generated spectrum. Consequently, these signals cannot be considered as strictly periodic, but rather as cyclo-stationary. Taking these into account, bearing defects are very difficult to detect employing conventional FFT [3]. Therefore, a wavelet based method is considered; it gives more effective results, as wavelet transform (WMT) provides powerful multi-resolution analysis in both time and frequency domains [2].

Ball bearing failures can be caused by several factors, such as incorrect design or installation, acid corrosion, poor lubrication and plastic deformation [4]. Faults as outer race, inner race, ball defect and cage defect, generate frequency components of specific characteristics, depending on the inner diameter, the outer diameter of the bearing, the frequency that the machine and the axis rotates, the number of the balls and the touch angle.

In this study, multiple defects [6-9] are imposed since a ball was hit in a random way. Therefore, a number of extra frequency components are expected to be observed in an FFT produced spectrum. Consequently, a healthy ball bearing is initially used and an electrical motor driven shaft rotates on it. The vibration signals are obtained for a period of 180 s via an accelerometer they are sampled and analyzed both by FFT and WTM. Then, the bearing is uninstalled, a ball is traumatized at random, it reassembled and it is tested employing an identical procedure as before. Then, the results of both analyses are compared. The experiment is repeated many times to ensure the statistical error minimization.

## 2. WAVELET TRANSFORM

The wavelet transform (WT) [1,5] is a method of converting a function (or signal) into a different form; it either makes certain features of the original signal more amenable to study or enables the original data set to be described more succinctly. A wavelet is a function satisfying certain mathematical criteria. There is a large variety of wavelets to choose from; in this study Mexican hat and Morlet wavelets were used.

The Mexican hat wavelet is described as:

$$\psi\left(\frac{t-b}{\alpha}\right)=\left[1-\left(\frac{t-b}{\alpha}\right)^2\right]e^{-1/2[(t-b)/\alpha]^2} \tag{2.1}$$

whereas, the general equation of wavelet transform is:

$$T(\alpha,b)=\frac{1}{\sqrt{\alpha}}\int x(t)\psi^*\left(\frac{t-b}{\alpha}\right)dt \tag{2.2}$$

where:

* denotes complex conjugation

$1/\sqrt{\alpha}$ is set for reasons of energy conservation (i.e. it ensures that the all wavelets, at every scale, have the same energy).

$\alpha$ and $b$ are dilation and location parameters respectively.

In (2.2) the transformed signal T($\alpha$, $b$) is defined on the a-b plane, where $\alpha$ and b are used to adjust the frequency and time location of the wavelet in Eq. (2.1); a small $\alpha$ produces a high-frequency (contracted) wavelet, when a high temporal resolution is required, whereas a large $\alpha$ produces a low-

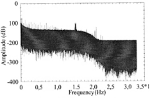


Fig. 3a) FFT healthy bearing 1

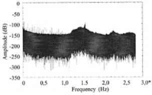


Fig. 3b) FFT defective bearing 1

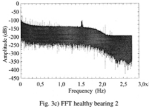


Fig. 3c) FFT healthy bearing 2

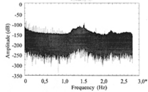


Fig. 3d) FFT defective bearing 2

This is what makes the selection of the a-parameter employed in the wavelet easy. Then, the continuous wavelet transform focuses on the specific band.

In fact, according to wavelet theory, for a Mexican hat wavelet, the $\alpha$ scale is required to be roughly a quarter of the period p to accentuate possible signal defects. Consequently, for 22500Hz, $\alpha$ must equal $1.11\times10^{-5}$. In this work $\alpha$ was set in the range between $10^{-5}$ and $5\times10^{-4}$[1]. Consequently,

$$f = 1/(4\alpha) \tag{4.1}$$

In figures 4a, 4b, 4c and 4c, the vertical axis of the upper plot represents the amplitude of the acceleration in m/s$^2$ and the vertical axis of the lower plot represents the a-parameter as described before.

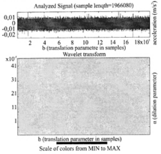


Fig. 4a) Mexican hat CWT for healthy bearing 1

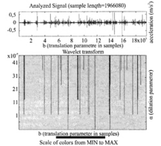


Fig. 4b) Mexican hat CWT for defective bearing 1

The horizontal axis in all cases represents the number of the samples. Thus, the time can be found multiplying the individual number with $1.525879 \times 10^{-5}$. For example, the $10^5$ sample is equal to $10^5 \times 1.525879 \times 10^{-5} = 15.255879$ s.

The differences in this spectrum are clear. For the healthy bearings (figs 4a-b) CWT is everywhere zero, contrary to the defective ones (figs 4c-d) where extra frequency components are to be observed in this band.

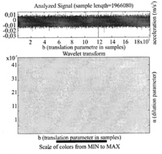


Fig. 4c) Mexican hat CWT for healthy bearing 2

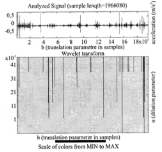


Fig. 4d) Mexican hat CWT for defective bearing 2

## 5. CONCLUSIONS

In this study, a wavelet based method for roller fault diagnosis has been presented.

Wavelet transform offers the possibility to detect specific faults on a roller bearing, such as faults in cage, rolling balls and inner and outer ring. Since the frequency of these is expected to be in a known band, the diagnosis could be done by selecting the proper value for the α-parameter which is directly connected with the frequency, as referred above.

The advantage of this method is the safe discrimination between the healthy and the faulty roller bearings using a low cost test procedure cost application.

## REFERENCES

Addison P. (2002), The illustrated wavelet transform handbook

Jing Lin, Liangsheng Qu (2000), Feature extraction based on Morlet wavelet and its application for Mechanical fault diagnosis.

Khalid F. Al-Raheem, Asok Roy, Ramachandran K.P., Harrison D.K., Grainger S. (2008), Rolling element bearing faults diagnosis based on autocorrelation of optimized: wavelet de-noising technique

Li C.J., McKee K. (2001), Bearing diagnostics.

Mallat S. (1998), A wavelet tour of signal processing.

Mori K., Kasashima N., Yoshioka T., Ueno Y. (1995), Prediction of spalling on a ball bearing by applying the discrete wavelet transform to vibration signals.

Prabhakar S., Mohanty A.R., Sekhar A.S. (2002), Application of discrete wavelet transform for detection of ball bearing race faults.

Purushotham V., Narayanan S., Suryanarayana A.N. Prassad (2005), Multi-fault diagnosis of rolling bearing elements using wavelet analysis and hidden Markov model based fault recognition.

Xinsheng Lou, Kenneth A. Loparo (2003), Bearing fault diagnosis based on wavelet transform and fuzzy inference.