DIAGNOSIS OF CRACKED GEARS USING THE EMPIRICAL WAVELET TRANSFORM

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Abstract

In the present work, the non-linear dynamic behavior of an eight degrees of freedom gear system is investigated in presence of defects. The main sources of excitation are the time varying mesh stiffness and backlash. The presence of a defect in the system vibratory behavior is detected by the Empirical Wavelet (EWT). A comparative study with the Empirical Mode Decomposition (EMD) is made which shows that the EWT is a powerful tool in the early fault detection for gears and gearbox.

Keywords: *gear, dynamic behavior, EWT, EMD, fault detection.*

1. Introduction

Currently, monitoring and diagnosis of rotating machines have become an absolute necessity because of their importance in most industrial sectors. Gears are important elements in rotating machines. They are used for changing the rotational speed between two shafts. The gears may contain defects that lead to limit their life and to increase the vibrations. The gear defects are caused either by inadequate lubrication or by an error in mounting or excessive loads.

The presence of crack on one or more teeth produces shocks in the vibration signal and sometimes by the presence of the non-stationarity of the signal.

The objective of this work is to develop a non-linear model gear with crack type defects. The defect is incorporated into the model by the time varying mesh stiffness considering the bending, shear, axial compressive Hertzian stiffness and fillet foundation deflection [1-3]. A nonlinear dynamic model of the gear system, with eight degrees of freedom, is investigated.

2. Mechanical Model

The gear pair model examined in this study is illustrated in figure1. It has an eight degrees of freedom (DOF), with masses m_n, base radius Rn (n=p,g), I_m/I_l is the mass moment of inertia of the motor/load, M1/M2 is the input/output torque, M_{pk}/M_{gk} is the stiffness moment of input/output coupling, M_{pc}/M_{gc} is the damping moment of input/output coupling. k_{xp}, k_{xg}, k_{yp} and k_{yg} represent the bearings stiffness, c_{xp}, c_{xg}, c_{xg} and c_{yg} represent the bearing damping. Cp/Cg is the shaft damping, k_p/k_g is the shaft stiffness. This model was proposed in ref [4] but in this work is used with backlash of coefficient 2b.

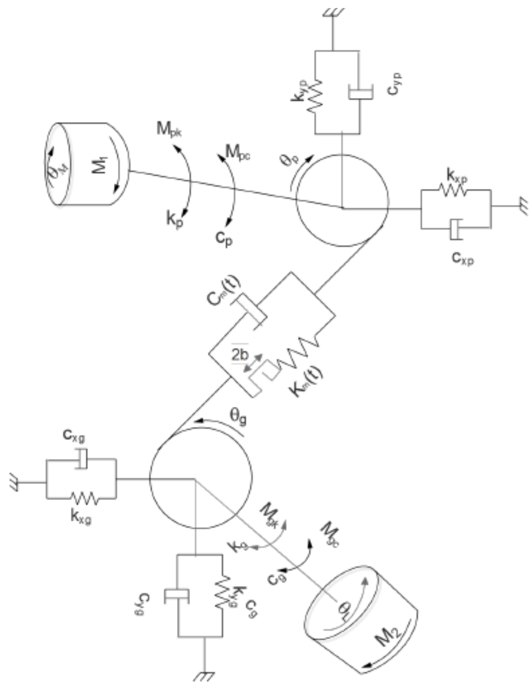

Figure 1 :8 DOF Gear model

The relative displacement u is:

$$u = DTE + (x_p - x_g)\cos(\alpha) - (y_p - y_g)\sin(\alpha) \quad (1)$$

Where $DTE = R_1\theta_1 - R_2\theta_2$

The contact force W is $W = K_m u + C_m \dot{u}$ (2)

The equations of motions are as follow:

$$I_m \ddot{\theta}_m = M_1 - k_p\left(\theta_m - \theta_p\right) - c_p\left(\dot{\theta}_m - \dot{\theta}_p\right) \quad (3)$$

$$I_l\ddot{\theta}_l = -M_2 + k_g\left(\theta_g-\theta_l\right)+c_g\left(\dot{\theta}_g-\dot{\theta}_l\right) \quad (4)$$

$$m_p\ddot{x}_p = -k_{xp}x_p - c_p\dot{x}_p \quad (5)$$

$$m_g\ddot{x}_g = -k_{xg}x_g - c_g\dot{x}_g \quad (6)$$

$$m_p\ddot{y}_p = -k_1 y_p - c_1\dot{y}_p + \sin(\alpha)W \quad (7)$$

$$m_g\ddot{y}_g = -k_2 y_g - c_2\dot{y}_g - \sin(\alpha)W \quad (8)$$

$$I_p\ddot{\theta}_p = k_p\left(\theta_m-\theta_p\right)+c_p\left(\dot{\theta}_m-\dot{\theta}_p\right)+R_pW \quad (9)$$

$$I_g\ddot{\theta}_g = k_g\left(\theta_g-\theta_l\right)+c_g\left(\dot{\theta}_g-\dot{\theta}_l\right)-R_gW \quad (10)$$

The dead zone is represented by piecewise continuous function f as follow:

$$f(v)=\begin{cases} v-b & if\ v\le b \\ 0 & if\ -b\le v\le b \\ v+b & if\ v\ge b \end{cases} \quad (11)$$

3. BACKGROUND

3. 1 Empirical Mode Decomposition

The Empirical Mode Decomposition (EMD) is an adaptive method, proposed by Huang et al. [5], aims to decompose a signal into a sum of N + 1 components called Intrinsic Mode Functions (IMFs) $f_k(t)$:

$$f(t)=\sum_{K=0}^{N} f_k(t) \quad (12)$$

3.2 Empirical Wavelet

The construction of the Empirical wavelets (EW) is equivalent to the construction of Band-pass filters. The empirical scaling function and the empirical wavelets are expressed by equations (2) and (3), respectively [6].

$$\hat{\phi}_n=\begin{cases} 1 & if\quad |\omega|\le\omega_n-\tau_n \\ \cos\left[\frac{\pi}{2}\beta\left(\frac{1}{2\tau_n}\left(|\omega|-\omega_n+\tau_n\right)\right)\right] & \text{if}\quad \omega_n-\tau_n\le|\omega|\le\omega_n+\tau_n \\ 0 & otherwise \end{cases} \quad (13)$$

4. RESULTS AND DISCUSSIONS

The equations of motion are simulated with parameters presented in table 1.

Table 1. Parameters of the pinion wheel set [7]

	pinion	Wheel
Teeth number	Z_1=25	Z_2=25
Module(mm)	2	2
Teeth width(mm)	20	20
Contact ratio	1.63	1.63
Rotational speed(Rpm)	2400	2000
Pressure angle	20°	20°
Young modulus E(N/mm²)	2.10^5	2.10^5
Poisson ratio	0.3	0.3

As the meshing change in the presence of a crack, A periodic fall in the TVMS value when meshing is in the defected area as illustrated in figures 2, 3.

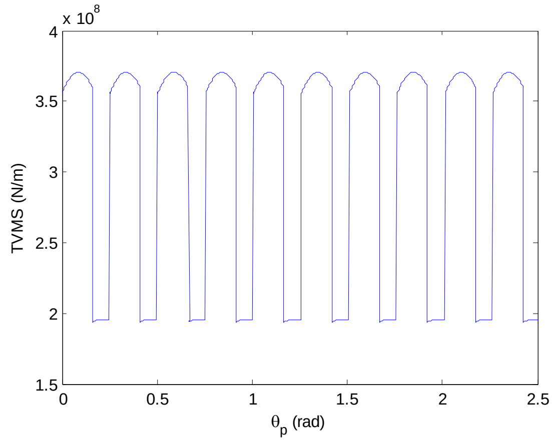

Figure 2. TVMS evolution in the healthy case

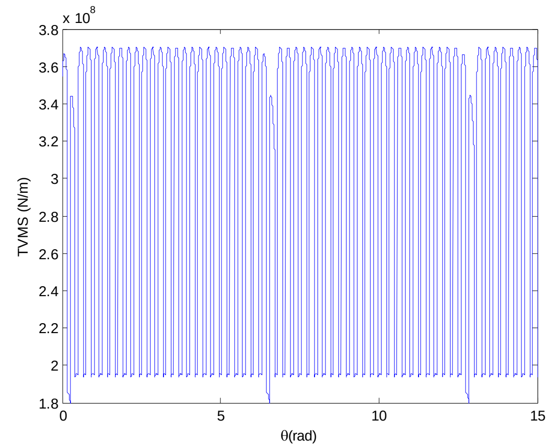

Figure 3.TVMS evolution in the cracked case

The figures (4-7) represent the EWT and EMD decomposition in healthy and cracked cases

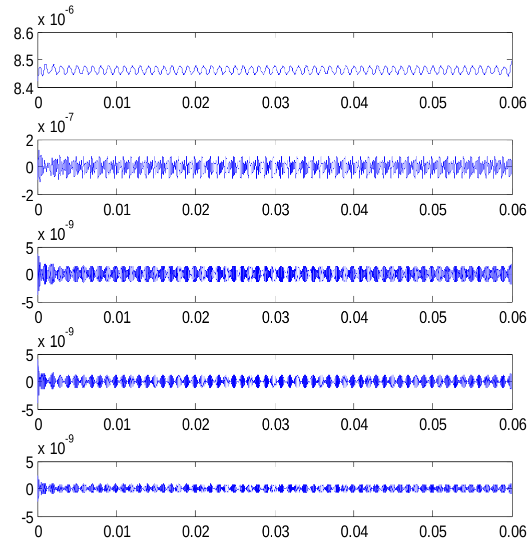

Figure 4. First five EWT components in healthy case

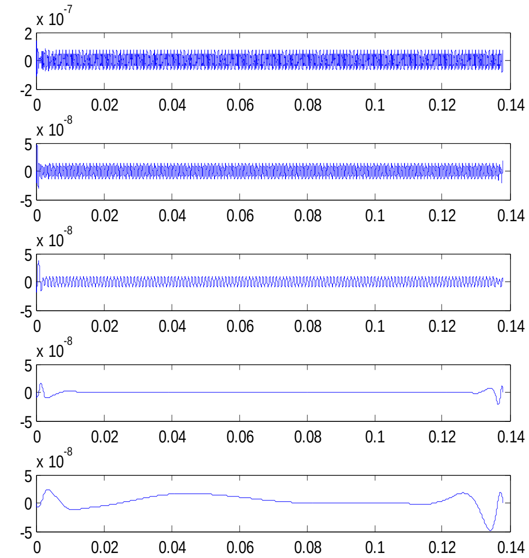

Figure 5.first five EMD modes in healthy case

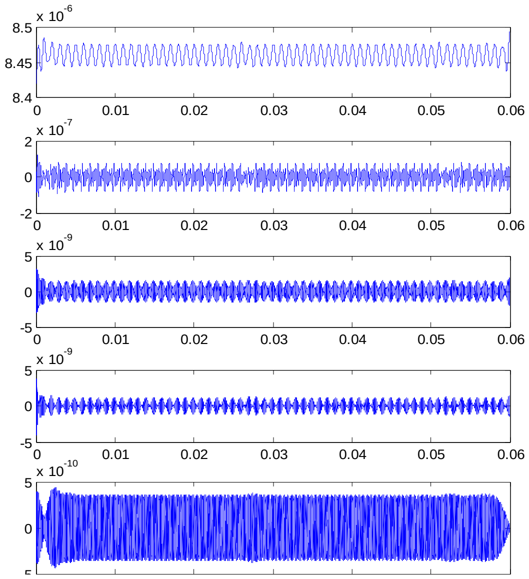

Figure 6. The five first EWT components in cracked case

As shown in figures (4-7) both of the two methods lets to separate signals components. The EWT is better relatively to the EMD. Indeed EMD needs more time of execution and gives more modes and it has a lack of mathematical theory.

5. CONCLUSION

In this work, an eight DOF gear system is investigated. The vibratory signals are obtained by a numerical simulation in MATLAB.A comparison is made between the EWT and EMD which showed that both the two methods lets to extract the signal feature but the EWT with more details. Then the EWT is a powerful tool in gear defect detection by separation of all signal components.

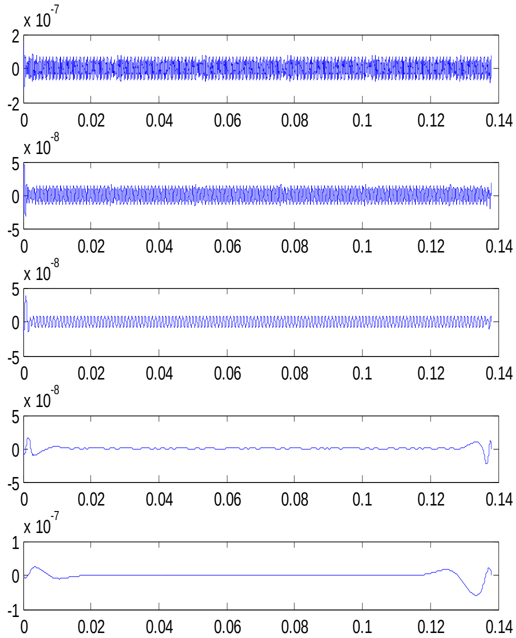

Figure 7. The five first EMD modes in cracked case

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