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 figure 1. It has an eight degrees of freedom (DOF), with masses $m_n$, base radius $R_n$ (n=p,g), $I_1/I_2$ is the mass moment of inertia of the motor/load, $M_1/M_2$ 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, $c_{xp}$, $c_{xg}$, $c_{yp}$ and $c_{yg}$ represent the bearing damping. $C_p/C_g$ 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.

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 $W = K_m u + C_m \dot{\theta}$ \quad (2)

The equations of motions are as follow:

$$I_1\ddot{\theta}_1 = M_1 - k_p(\theta_1 - \theta_2) - c_p(\dot{\theta}_1 - \dot{\theta}_2) \quad (3)$$
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\[ I_{\theta_{g}} = -M_2 + k_g \left( \theta_g - \theta_1 \right) + c_g \left( \dot{\theta}_g - \dot{\theta}_1 \right) \]  
(4)

\[ m_p \dot{\theta}_g = -k_{sp} x_p - c_p \dot{x}_p \]  
(5)

\[ m_y \ddot{x}_g = -k_{sp} y_g - c_y \dot{x}_g \]  
(6)

\[ m_{p,y} \ddot{x}_p = -k_{sp} y_p - c_{1y} \dot{x}_p + \sin(\alpha)W \]  
(7)

\[ m_{s,y} \ddot{x}_s = -k_{sy} y_s - c_{1y} \dot{x}_s \]  
(8)

\[ I_{\theta_{g}} = k_p \left( \theta_m - \theta_p \right) + c_p \left( \dot{\theta}_m - \dot{\theta}_p \right) + R_p W \]  
(9)

\[ I_{\theta_{s}} = k_s \left( \theta_s - \theta \right) + c_s \left( \dot{\theta}_s - \dot{\theta} \right) - R_s W \]  
(10)

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.

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) \( f_k(t) \): 

\[ f(t) = \sum_{k=0}^{N} f_k(t) \]  
(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].

\[ \phi_n = \cos \left[ \frac{\pi}{2} \beta \left( |\omega| \omega_n - r_n \right) \right] \]  
(13)

4. RESULTS AND DISCUSSIONS

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

<table>
<thead>
<tr>
<th>Teeth number</th>
<th>Module (mm)</th>
<th>Teeth width (mm)</th>
<th>Contact ratio</th>
<th>Rotational speed (Rpm)</th>
<th>Pressure angle</th>
<th>Young modulus E (N/mm²)</th>
<th>Poisson ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>pinion</td>
<td>Wheel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z₁ = 25</td>
<td>Z₂ = 25</td>
<td>2</td>
<td>1.63</td>
<td>2400</td>
<td>20°</td>
<td>2.10⁵</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Figure 2. TVMS evolution in the healthy case

Figure 3. TVMS evolution in the cracked case

Figure 4. First five EWT components in healthy case
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 let's 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.

References


