UDC 681.518.5:629.735.03(045)

S.S. Tovkach, Cand. Of Sci.(Engineering)
(National Aviation University, Ukraine)
S.V. Yenchev, Cand. Of Sci.(Engineering)
(National Aviation University, Ukraine)

Wavelet-Based Algorithm for Detection the Node Faults of Aviation Engine

An approach of gas turbine engine diagnostic system for improving the efficiency of functioning the electronic control system of aviation engine based on wavelet algorithm has presented. The computational algorithm can perform the identifying power frequency variations and integer harmonics using the complex Morlet wavelet. It can be applied to detect the harmonics and wavelet ridges in a power signal to develop the new principles of correct location the faults of the engine.

Introduction. Improving the reliability and maintainability of gas turbine engines is becoming more critical to end users concerned with reducing costs and increasing availability. A Condition-based Maintenance strategy promises to reduce the costs associated with scheduled maintenance by monitoring the actual condition, or health, of the component and replacing component only when necessary and at optimally scheduled maintenance times.

Vibration-based features are of particular importance in determining the condition of the nodes within this system and are the focus of this paper. The accuracy of bearing health predictions is critical to a robust and effective Prognostic and Health Management implementation. Substantial research has focused on the development of robust and accurate features that can be used to increase the accuracy of health predictions; however, many of these developments have occurred in laboratory settings. Although suitable for proof-of-concept validation, the idealized laboratory test rig is often a simplified form of the target system, such as a gas turbine engine.

Confounding issues, such as indirect vibration transmission path, operating condition issues, and noise sources, are often absent from the development laboratory. Complete validation of the feature or sensor is therefore possible only through actual engine tests. Therefore, we used data collected from an actual gas turbine engine, mounted in a full scale test cell, to validate the developed techniques.

The goal of this research is, taking into account the wave resolution of a power signal, to determine and predict early stage node failures, which will therefore affect turbine reliability and life-cycle costs both positively and dramatically for ensure unimpeded engine operation.

Harmonics frequency detection. Given a signal $f(t)$ represented as

$$f(t) = a(t)\cos\phi(t), \tag{1}$$

The dilated and translated wavelet families are represented as

$$\psi_{u,s}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-u}{s}\right) = e^{-j\xi u} g_{s,u,\xi}(t), \tag{2}$$

where $g_{s,u,\xi}(t) = \sqrt{s}\, g\big((t-u)/s\big) e^{j\xi t}$; $\xi = \omega / s$.

The wavelet transform of the signal function $f(t)$ in (1) is given as,

$$W\ f(u,s) = \frac{\sqrt{s}}{2} a(u) e^{j\phi(u)} (\hat{g}(s[\xi - \phi'(u)]) + \varepsilon(u,\xi)), \tag{3}$$

where $\hat{g}(\omega)$ represents the Fourier transform of the function $g(t)$.

The corrective term $\varepsilon(u,\xi)$ in (3) is negligible if $a(t)$ and $\phi'(t)$ in (1) have small variations over the support of $\Psi_{u,s}$ in (2) and if $\phi'(u) \geq \Delta\omega / s$.

If a power signal contains only a single frequency, the corrective term can be safely neglected. However for a power signal containing harmonics from low frequency to high frequency, the corrective term will contribute to the wavelet coefficients, making the frequency detection not straightforward.

The instantaneous frequency is measured from wavelet ridges determined over the wavelet transform. The normalized scalogram defined by [2]

$$\frac{\xi}{\eta} P_w f(u,\xi) = \frac{|W\ f(u,s)|^2}{s} \tag{4}$$

is calculated with

$$\frac{\xi}{\eta} P_w f(u,\xi) = \frac{1}{4} a^2(u) \left| \hat{g}\left(\eta \left[1 - \frac{\phi'(u)}{\xi} \right] \right) + \varepsilon(u,\xi) \right|^2. \tag{5}$$

Since $|\hat{g}(\omega)|$ in (5) is maximum at $\omega = 0$, if one neglects $\varepsilon(u,\xi)$, (5) shows that the scalogram is maximum at

$$\frac{\eta}{s(u)} = \xi(u) = \phi'(u). \tag{6}$$

The corresponding points $(u, \xi(u))$ calculated by (4,6) are called wavelet ridges. For the CMW, $g(t)$ in (2) is a Gaussian function. Since the Fourier transform of a Gaussian function is also a Gaussian function, the wavelet ridge plot exhibits a Gaussian shape. Figure 1 shows the wavelet ridges plot for the 40 Hz signal.

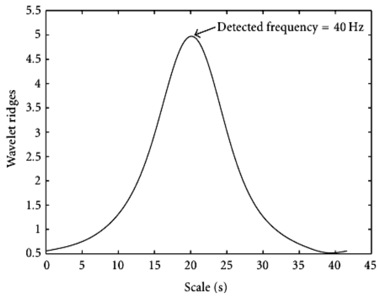

Figure 1. Wavelet ridges plot for a 40 Hz signal

It can be seen that the wavelet ridges can accurately detect the signal frequency. Figure 2 shows the wavelet ridges plot for the detection of the 40 Hz signal component in the signal containing frequencies at 40 Hz and 240 Hz, respectively.

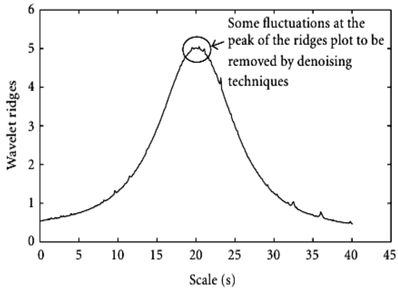

Figure 2. Wavelet ridges plot for a 40 Hz signal

There are some fluctuations at the peak of the wavelet ridges, introducing small errors in the frequency detection. The fluctuations are due to imperfection of the filters produced by the dilated CMWs and the corrective term in (3).

Discrete Stationary Wavelet Transform (DSWT) is adopted to remove the fluctuations of the wavelet ridges. In view of the shape of the wavelet ridges, the Symlet2 wavelet developed by Daubechies is used. It is found that a decomposition level of 5 is sufficient to remove the fluctuations.

Figure 3 shows the denoised wavelet ridges plot of the signal containing frequencies at 40 Hz and 240 Hz, respectively.

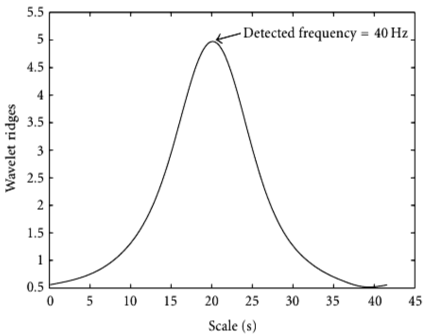

Figure 3. Denoised wavelet ridges plot of the wavelet ridges plot in Figure 3

The 40 Hz frequency component of the signal is accurately detected by the wavelet ridges after denoising.

The proposed harmonics detection algorithm is presented in Figure 4.

The proposed algorithm is implemented with Matlab software.

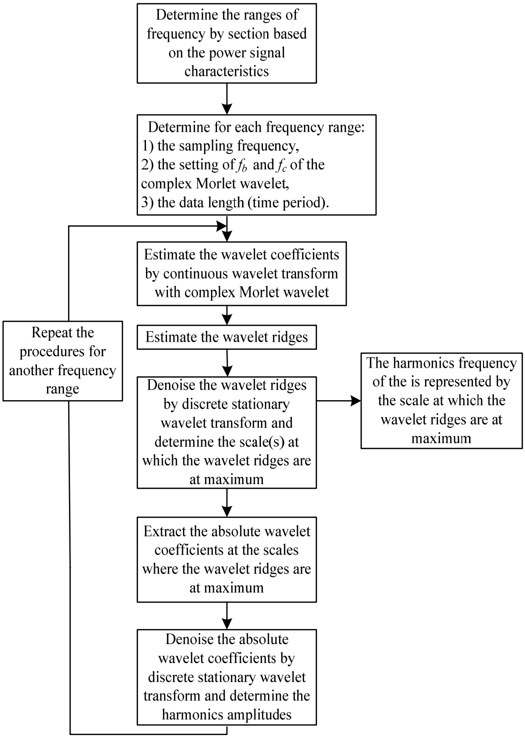

Figure 4. The flow chart of the proposed harmonics detection algorithm

Conclusion. The proposed harmonics detection algorithm is able to identify the frequency and amplitude of harmonics in a power signal to a very high accuracy.

The accuracy of the proposed harmonic detection algorithm has been verified by tests conducted on a computer-simulated signal and a field signal.

It is concluded that node detection is highly affected by the hybrid diagnostic techniques that are implemented, as well as the bandwidths chosen for scrutiny.

In other words, the proper selection of the vibration bands and diagnostic techniques will result in better estimation of node health.

References

1. *Huang, S.-J.; Hsieh, C.-T.; Huang, C.-L.* Application of Morlet wavelets to supervise power system disturbances. IEEE Transactions on Power Delivery. 2009. Vol. 14, N. 1. P. 235–241.

2. *Enchev S.V., Tovkach, S.S.* Wavelet-based algorithm for detection of bearing faults in a gas turbine engine. Proceedings of National Aviation University. K.:NAU, 2014, P.88-96.