The vibratory diagnosis of gearboxes with latest tools developed by Dynae: the gear processing module

Xavier THOMAS[1], François COMBET[2]

[1]Dynae
29 rue Condorcet
38090 Villefontaine, France
xthomas@dynae.fr

[2]Dynae
18 rue de Thann
68057 Mulhouse, France
fcombet@dynae.fr

Abstract

Vibration analysis of gearboxes requires the use of advanced signal processing tools (amplitude and phase demodulation, filtering, time synchronous averaging, and so on…). If these techniques are known and mastered for decades, the application of these tools to vibration analysis of gears requires many steps of validations that restrict its systematic implementation in industry.

The new gear processing module, incorporated into our DynamX analysis software, allows to quickly edit the dynamic meshing profiles by automating the steps of calculations, while leaving the user controlling the parameters

.

Furthermore, the implementation of a tool for generating a virtual tachometer from the vibration of the meshing signal now eliminates the use of a tachometer measurement usually required, which was the main obstacle to the deployment of these technologies as part of the conditioning monitoring.

1 Introduction

Vibration analysis on a gearbox, in the context of conditional maintenance is often limited to the search of a typology of default thanks to a spectral analysis. If this technique appears relevant at first glance, it quickly finds its limits, particularly on complex machinery with several gear trains, where many sources can mask the appearance of low energy faults but are extremely serious for the durability of an installation such as the appearance of a crack on a tooth.

The analysis of the dynamic meshing profiles representing the fluctuations of meshing pressure on each tooth is a particularly effective method which requires the use of advanced processing tools ranging from conventional spectral analysis to demodulation and time synchronous averaging. Although these techniques are for the most part well-known and mastered for decades, they don't manage to be used as systematic processing because of the numerous operations to be carried out that require a rigorous methodology and lots of steps of validation of results. In fact, only complex machinery of high power and with high financial stakes has been fully studied with tools developed under Matlab. If this programming language allows the rapid development of processing tools, it poses the problem of validation of algorithms and monitoring of evolutions. Thus, only a few initiates had access to these analysis tools.

To meet this need of automation of the processing and validation of results, Dynae has developed in 2016 a new gear processing module, incorporated in our dynamic signal processing software DynamX . Based on the research and development of several of our engineers, Dynae has been able to commercialize this processing module that allows the automation of treatments, incorporating new tools, never developed at an industrial stage.

2 Description of the main tools implemented in the module

2.1 Rotational speed management without phase reference

Since the vast majority of industrial machineries are not equipped by tachometers, the analysis of the gears was often based on the assumption of a stability of the rotation speed. The installation of an external one-pulse-per-revolution tachometer requiring accessibility and availability of the installation is essential for the validity of treatments of synchronous averaging. Thus, the systematic use of this kind of processing over all installations depended on the knowledge of the instantaneous speed of the machines. In order to do this, the work carried out made it possible to extract the instantaneous phase of the meshing vibration in the accelerometer records in order to generate virtual tachometer signals associated with the input and output shaft lines of the considered gears.

The speed estimation algorithm working on the phase of the gearmesh emergence, it is limited in frequency by the presence of the modulation sidebands link to the rotations of the input and output shafts of the gear train [1,2].

The frequency band B in which algorithm can identify the fluctuations of a harmonic of the gearmesh frequency is defined by:

$$B = \frac{F_{eng}}{\max[Z_1, Z_2]} = \frac{H_{eng}}{\mathrm{h} * \max[Z_1, Z_2]} \qquad avec\ H_{eng} = h * F_{eng}$$

Thus, the maximum variation rate of the velocity, which is admissible by the algorithm for the determination of rotational speed from a harmonic of the gear frequency, is:

$$\delta V_{max}(\%) = 100 * \frac{\mathrm{B}}{H_{eng}} = \frac{100}{\mathrm{h} * \max[Z_1, Z_2]}$$

In order to optimize the duration of the signal available for treatments, the longest period meeting the criteria of speed evaluation is determined by looking for a deviation to the mean less than $\frac{\delta V_{max}}{2}$

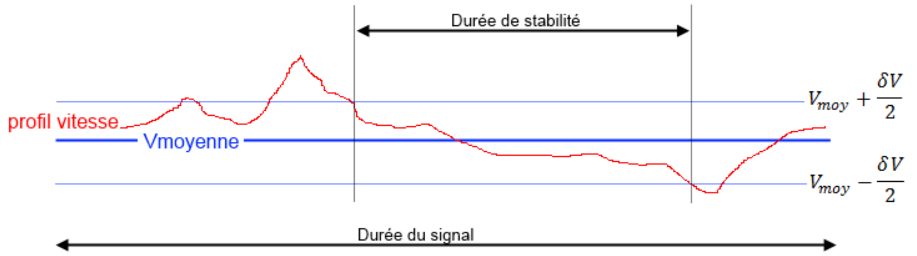


Figure 1: Determination of the longest period of speed stability

At the output, the module has a vibratory record having relative speed stability and two virtual tachometers for phase references associated with the input and output shaft lines.

2.2 Edition of the mesh profiles

The editing of the dynamic meshing profiles is based on synchronous averaging techniques. This technique is particularly effective to highlighted periodic waveforms from a noisy signal. However, 2[nd] order cyclostationary information is also important for the diagnosis of gears [3]. Thus, to analyze the random components, the synchronous variance is extracted from the signals.

The time synchronous averaging is defined by:

$$M_x(t) = \frac{1}{N}\sum_{k=0}^{N-1} x(t + kT)$$

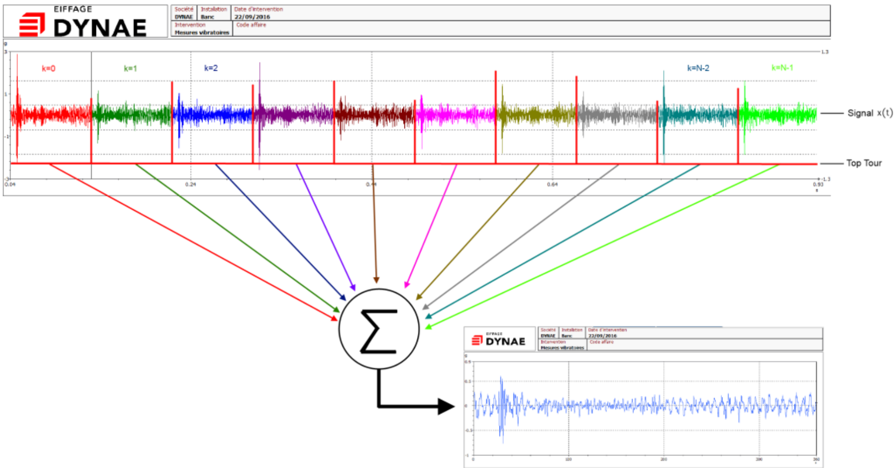


Figure 2: Principle of time synchronous averaging

After the synchronous averaging at the rotation frequencies of the input and output shaft lines, the gear module enables graphical parameterization of the band pass filtering to be applied. Thus, the user can select the harmonic of the meshing frequency and the number of sidebands to be considered. This graphical approach allows the user to control the symmetries of the sidebands and thus limit the impact of the transfer function of the structure inherent in vibration measurements. The dynamic profiles of the meshing are then real time updated as well as the associated modulation rates.

Figure 3: Analysis window of the gear processing module

The random part of the averaged signal is exploited through the synchronous variance which makes it possible to highlight information hidden by the synchronous averaging. Thus, high-frequency shocks related to the deterioration of the surface of teeth will be better revealed by the synchronous variance.

Synchronous variance is defined:

$$V_x(t) = \frac{1}{N}\sum_{k=0}^{N-1} |x(t + kT) - M_x(t)|^2$$

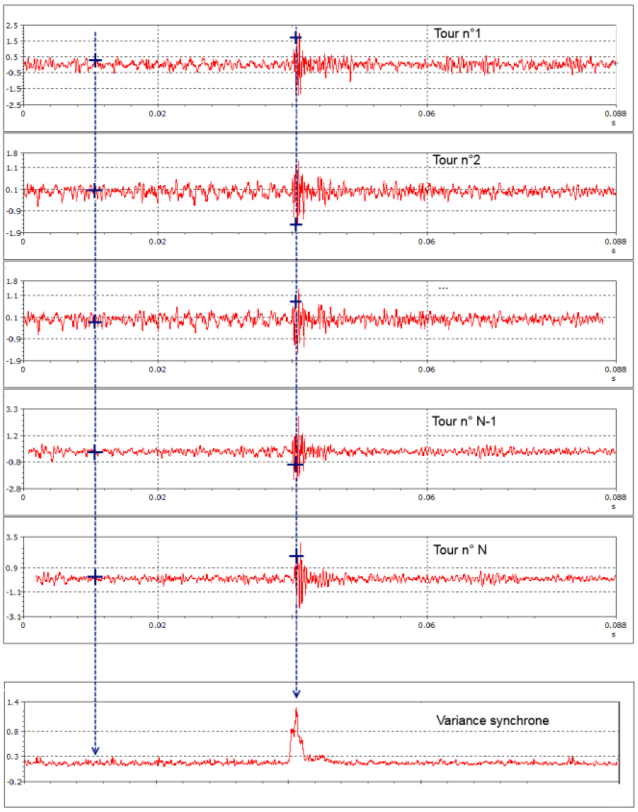


Figure 4: Principle of time synchronous variance

The synchronous standard deviation profile is then presented in the gear module as additional information for gear diagnosis.

2.3 Detection of tooth shocks

Another tool implemented in the gear processing module is the detection of shocks associated with the meshing of the pinion / wheel considered. This step is based on the use of spectral kurtosis using resolutions adapted to the studied meshing [4,5].

Spectral kurtosis is a tool particularly suitable for the search of impulsions in time signals. The principle is to generalize the search for impacts related to the appearance of a crack on a gear by a search of a transient phenomenon in a raw data. The power of this tool is to make it possible to identify the frequency band allowing the best reading of the information.

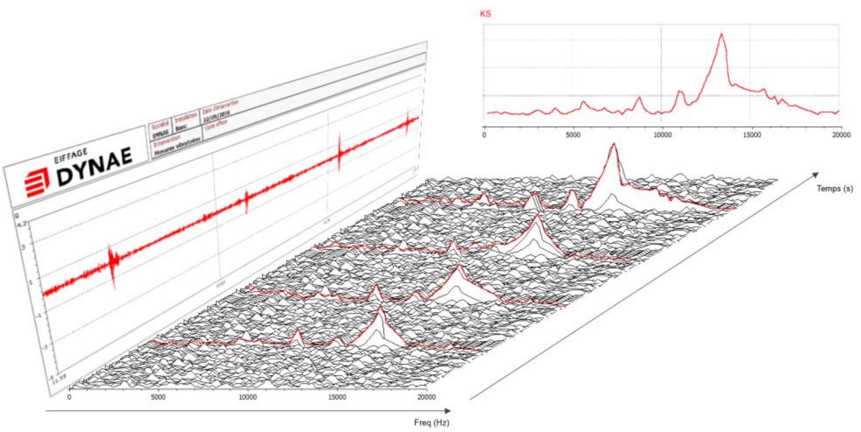


Figure 5 : Principle of spectral kurtosis

In the module, the information of the number of teeth of the pinion and wheel makes it possible to refine the spectral kurtosis for three resolutions. The band corresponding to the maximum KS is selected to define the bandpass filter to be applied to the signal.

Figure 6: Example of spectral kurtosis calculated for three different resolutions

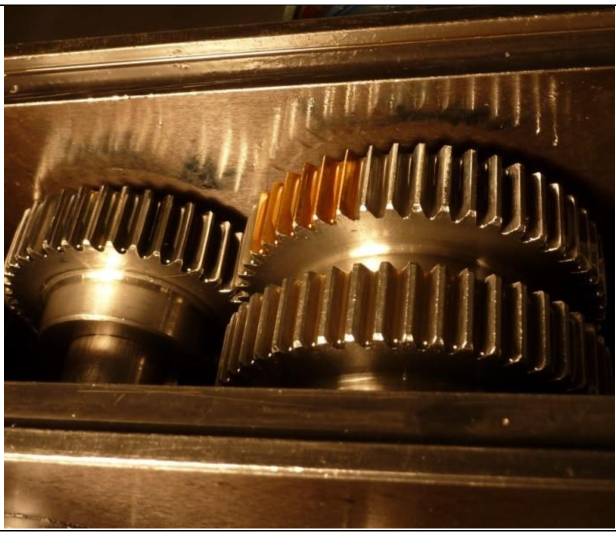
A synchronous averaging is then applied to the filtered signal to distinguish if the shocks are effectively related to the concerned gear train and identify which wheel carries the defect.

3 Module validation on a test bench

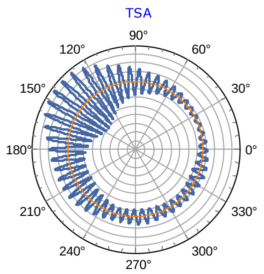
Measurements on a test bench helped to validate the new tools implemented in the module. Two gears, each one having identified defects, were analyzed.

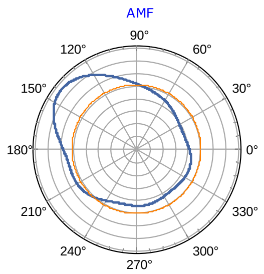
3.1 Eccentric wheel

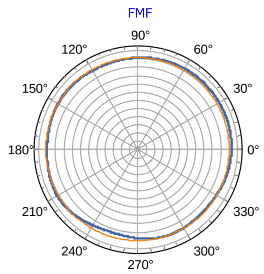
A first gear train with an eccentricity on the low speed wheel has validated the module's features dedicated to the generation and analysis of the dynamic meshing profiles. Indeed, the typology associated with an eccentricity of a pinion is a modulation in amplitude and frequency of the carrier frequency. The analysis of the meshing profiles enables a fine analysis of the mechanical forces and quantification of these phenomena. Thus, the wheel section affected by the eccentricity fault was clearly demonstrated



wheel 50 teeth







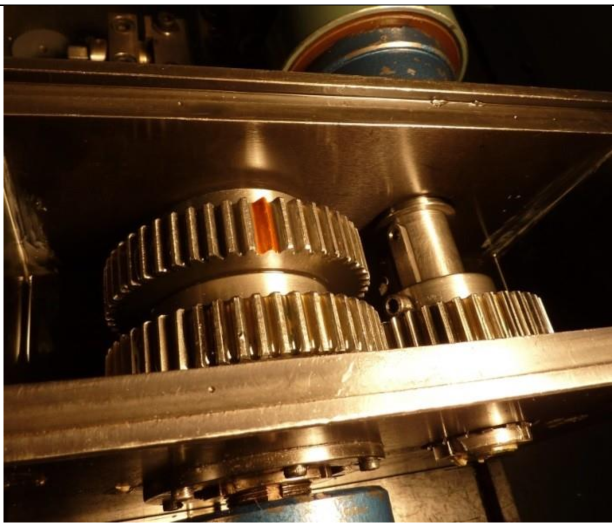
Vrms TS = 0,1244	AMR(%) = 130,7%	FMR(%) = 3,8%
(H=1, nbL=5)	AMRrms(%) = 104,6%	FMRrms(%) = 1,9%

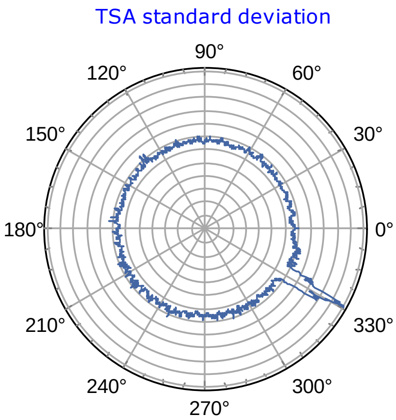
Figure 7: Meshing profiles edited with the gear processing module - eccentricity of the 50 teeth wheel

3.2 Broken tooth

The second configuration being tested was a low speed wheel whose one tooth was filed down to change its profile. The typology expected on this kind of default is a periodic shock whose period is linked to the rotation of the low speed shaft. The part of the gear processing module dedicated to the shock detection in the time signals has been validated. The pulse search algorithm based on the spectral kurtosis combined with a synchronous averaging of the envelope of the filtered signals clearly revealing the searched information.

We note that the synchronous standard deviation also reveals the information of shock due to the broken tooth.





Shock profile in band B=(12400 - 13200)Hz, KS = 127,88

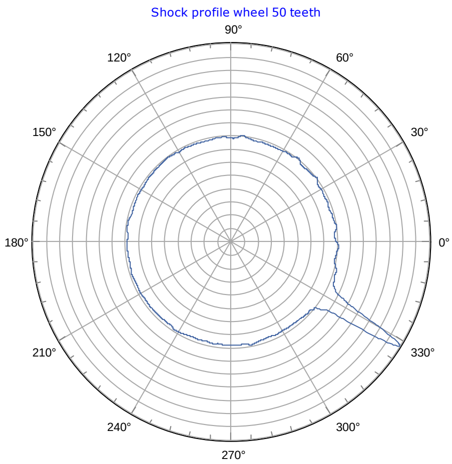


Figure 8: Shock profile edited with the gear processing module – broken tooth in the 50 teeth wheel

4 Conclusion

The new gear processing module represents a real advance in the practice of vibration analysis of gear trains. It makes the analysis more relevant in order to optimize the diagnosis in a context of condition monitoring by vibration experts.

References

[1] F. Bonnardot, M. El Badaoui, R.B. Randall, J. Danière, F. Guillet, *Use of the acceleration signal of a gearbox in order to perform angular resampling (with limited speed fluctuation)*, Mechanical Systems and Signal Processing 19 pp 766–785, 2005.

[2] F. Combet, L. Gelman, *An automated methodology for performing time synchronous Averaging of a gearbox signal without speed sensor*, Mechanical Systems and Signal Processing 21 (6) pp 2590–2606, 2007.

[3] J. Antoni, F. Bonnardot, A. Raad, M. El Badaoui, *Cyclostationary modelling of rotating machine vibration signals*, Mechanical Systems and Signal Processing 18 pp 1285–1314, 2004.

[4] J. Antoni, R.B. Randall, *The spectral kurtosis: application to the vibratory surveillance and diagnostics of rotating machines*, Mechanical Systems and Signal Processing 20 (2) (2006) 308–331.

[5] F. Combet, L. Gelman, *Optimal filtering of gear signals for early damage detection based on the Spectral Kurtosis*, Mechanical Systems and Signal Processing 23 (3), pp. 652-668, 2009.