INNOVATIVE PROCEDURE FOR MACHINE TOOLS DIAGNOSIS

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Rezumat. *Achiziția de date în vederea determinării comportării dinamice a maşinilor a stat dintotdeauna la baza aplicațiilor din domeniul vibraiilor. Cu toate acestea, nu este suficientă achiziția de date, este nevoie de analiză, procesare şi interpretare a datelor brute si transformarea lor în informații utile. Această lucrare prezintă importanța înțelegerii diferitelor semnături ale vibrațiilor şi modul corect de extragere a datelor pentru a efectua analiza de trend. Având informațiile corecte date de semnătură, devine posibilă realizarea unui plan de mentenanță care să guverneze o fabrică şi procesul de produție al acesteia.*

Abstract. *Dynamic data acquisition has always been at the heart of every sound and vibration application. However, it is not enough to simply be able to acquire data, you also have to be able to analyze, process, and interpret the raw data into meaningful content. This paper presents the importance of understanding the different vibration signatures and how to properly extract them for trending analysis. With proper signature information, it becomes possible to tabulate specific metrics which can drive plant maintenance or production schedules.*

Keywords: diagnosis, vibration level, frequency spectrum, envelope analysis, cepstrum.

1. Introduction

Rotating/reciprocating machinery produces vibration signatures depending upon the mechanism involved. Faults may occur at motor, rolling element bearings, gearboxes, belts, fans and other electrical/mechanical components. It is strongly necessary to detect these problems at an early stage and to avoid serious damage and catastrophic failure. The purpose of analysis is to identify the fault frequencies so that root cause can be addressed and corrective action can be taken. Vibration analysis is a way of getting information from the inside of operating machines without having to shut them down [2].

Knowledge of developing and existing causes of vibration leads to the possibility of establishing measures to eliminate or to reduce them, which would reflect the improvement of machine tool qualitative performances. The most common way of identifying the possible sources of vibration is achieved by studying the operating process; the identification is limited, in the frequency spectrum, at finding the main and harmonic frequencies specific to these sources.

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Requiring low costs, this method produces reliable results and generates information for early recognition of faults and imbalances, an optimal planning of maintenance action and the prevention of damage or disruption of production processes.

2. Fault diagnosis

Once a significant change indicating a potential fault has been detected, it is usually necessary to perform other signal processing techniques to make a diagnosis of the fault(s), which depend greatly on the type of fault expected. The type of analysis to be applied depends on the type of fault, and so it is interesting to investigate how various faults manifest themselves in the vibration signal [4].

The first step in any vibration application is to understand the system you are trying to monitor and the vibration signals present in it. After this has been defined, the next step is to choose the correct algorithm for extracting the signal feature of interest from the raw signal.

3. Signal processing techniques

Once faults have been detected, it is necessary to apply a range of signal processing techniques to the vibration signals to try to determine the reasons for the spectral change. In the following, a number of classical and newer techniques are reviewed.

3.1. Frequency analysis - FFT

Frequency analysis is the most commonly used method for analyzing a vibration signal. The most basic type of frequency analysis is an FFT, or Fast Fourier Transform, which converts a signal from the time domain into the frequency domain. The product of this conversion is a power spectrum and shows the energy contained in specific frequencies of the overall signal. This is quite useful for analyzing stationary signals whose frequency components do not change over time.

Despite its common use, there are many downfalls to just using frequency analysis because its results, such as a power spectrum or total harmonic distortion, contain only the frequency information of the signal (see Figure 1). Although the frequency behaviour of the two signals is different, their frequency spectra (left) computed by the FFT are identical because the energy at individual frequencies in each signal is the same.

The second limitation of the FFT is that it cannot detect transients or short spikes in the signal (see Figure 2). Transients are sudden events that last for a short time in a signal and usually have low energy and a wide frequency band, so you might not be able to recognize their existence in the frequency domain. In Figure 2, Signal 2 contains a transient. Despite the presence of the transient, the power spectra of both signals are identical because the energy of this transient is spread over a wide range of frequencies [5].

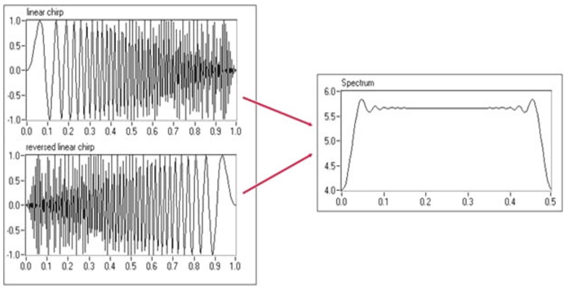

Fig. 1. The same frequency spectrum for two signals.

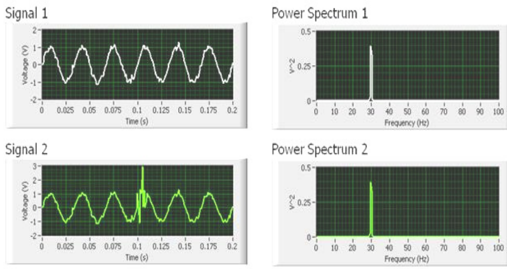

Fig. 2. The transient in Signal 2

3.2. Envelope analysis

Envelope analysis is a useful tool to extract the sidebands caused by amplitude modulation. The fundamentals of envelope analysis are briefly introduced with examples of rolling element.

For example, the faults in a defective rolling bearing signal are difficult to diagnose through a simple FFT spectrum analysis as they are cyclo-stationary (periodically time-varying statistics), have very little energy and overwhelmed by noise and other vibrations. Also, the resonances enhance higher frequencies and any jitter removes the high frequencies in raw signal but showing them in the envelope [2].

Figure 3 shows typical acceleration signals produced by localized faults in the various components of a rolling element bearing, along with the corresponding envelope signals produced by amplitude demodulation. The diagram illustrates that as the rolling elements strike a local fault on the outer or inner race, a shock is introduced that excites high frequency resonances of the whole structure between the bearing and the response transducer. The same happens when a fault on a rolling element strikes either the inner or outer race [1].

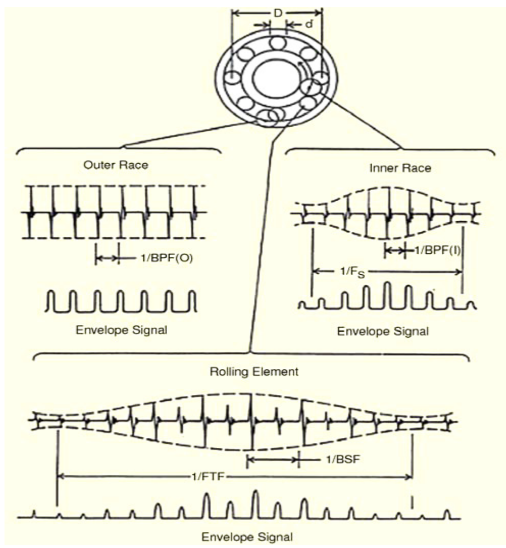

Fig. 3. Acceleration and envelope signals.

Figure 4 shows a real acceleration signal acquired on a bearing with outer race fault. The running speed of the shaft is 1800 RPM. The sampling rate is 102.4 kHz. In Figure 4, a we can see the spikes caused by balls passing the local fault of the outer race. In the spectrum, Figure 4, b, it is clearly seen that sidebands around *fc* at 948 Hz. In Fig. 4 (c) the envelope frequency at 105.45 Hz (= 1/0.0095) and its second harmonic at 210.9 Hz are correctly extracted in the envelop spectrum.

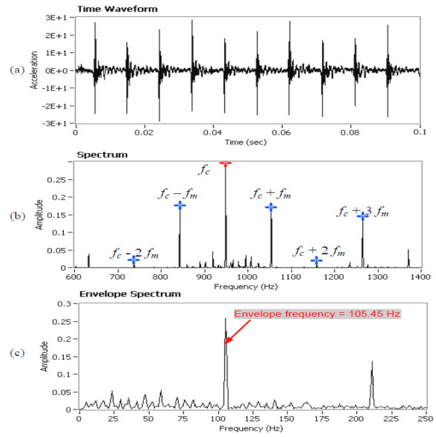

Fig. 4. a. Acceleration signal;
b. The carrier frequency and its sidebands;
c. Envelope frequency shows the BPFO.

3.3. Cepstrum analysis

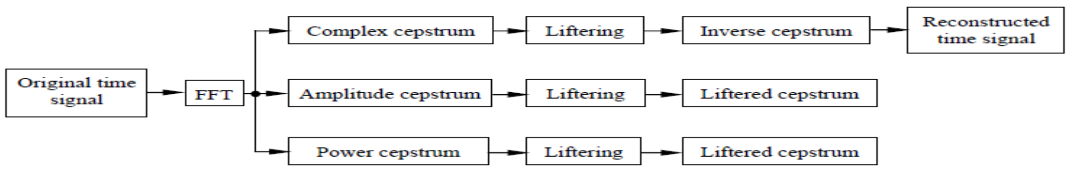

Fig. 5. Procedures of performing cepstrum analysis.

Cepstrum, which is an anagram of spectrum, is a nonlinear signal processing technique used to identify and separate harmonic families in the spectra of gearbox and bearing signals. Cepstrum also finds it application in echo cancellation and speech signal processing.

Flowchart in Figure 5 demonstrates the procedures of three different cepstrum forms. This figure can be used as a guideline for performing the cepstrum analysis [2].

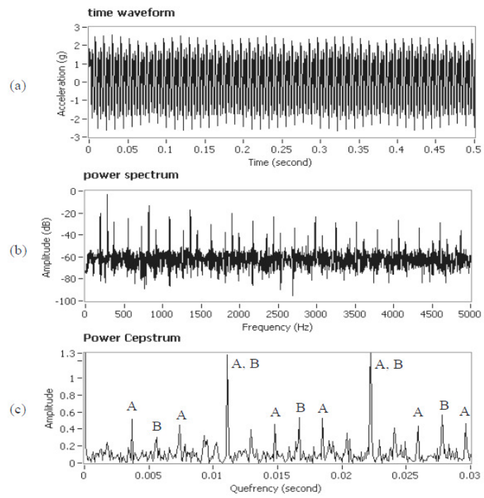

Fig. 6. a. A typical gearbox signal; **b.** power spectrum; **c.** power cepstrum.

Figure 6,a illustrates a typical gearbox signal. The two gears have 18 and 27 teeth, respectively. The input shaft was rotating at a speed of 10 Hz (600 RPM).

Therefore in it power spectrum it can be clearly seen that there are two strong components at the 18th and 27th orders, or more precisely, at 180 and 270 Hz. These two components and their harmonics generate two harmonic families which are mingled in the power spectrum such that they are not easily distinguished, as shown in Figure 6, b. Figure 6, c is the power cepstrum calculated from the power spectrum shown in Fig. 6, b. Please notice that the *quefrency* axis is in second because it is calculated using the inverse transform of a signal in the frequency domain. As a result, the cepstrum has an appearance to a time waveform [3].

4. Experimental measurements

As we said before, when vibration component dominates the overall spectrum at a certain frequency, the overall level of vibration may be a good parameter for early detection of defects in rotating mechanical parts of machines and equipments in industrial engineering.

To this end, we have conducted a series of measurements. Figures 7 and 8 show the measurement equipment mounted on two different machines: a drilling machine, having gear box defects (see Figure. 7) and a milling machine, having troubles with the spindle-bearings assembly, because of the use of a single bearing, at one end (see Figure 8). Data acquisition was done at no load (without cutting process) for different spindle speeds, using Vibroport 41, which is a data acquisition equipment with two channels.

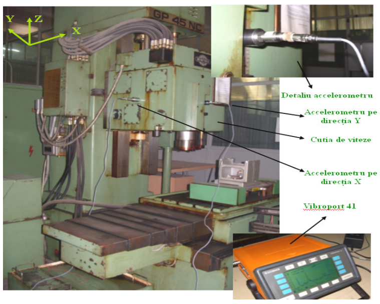

Fig. 7. Drilling machine GP 45 NC

Fig. 8. Milling machinePC MILL 100

The results are presented in the figures below. In Figure 9 you can see the frequency spectrum for drilling machine, at a speed of 450 rpm. After eliminating the natural frequencies of the gears (calculated by using Finite Element Analysis) and the gear frequencies from the spectra, it was concluded that the highest frequency was the result of a gear defect. Frequencies of interest were discovered on the spectrum of the milling machine also (see Figure 10): 25.391 and 100 Hz frequencies are derived from the bearings of the motors shaft; 41 Hz and 140.6 Hz frequencies have as a source the machines compressor (to check this, measurements were made only on the compressor); the higher frequencies are possible turbulences in the electric engine cooling system. Another type of analysis was conducted on this machine, and that is trend analysis. The result is being able to identify the fault speeds of the shaft, in the area of speeds 200…5000 rpm (see Figure 11). So, it is recommended to avoid the following speeds: 2400 rpm, 4000 rpm, 200 rpm, 500 rpm, 2300 rpm.

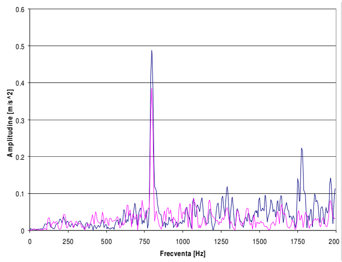

Fig. 9. Frequency analysis – Drilling machine.

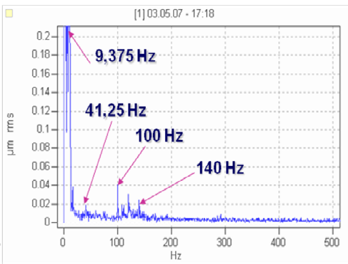

Fig. 10. Frequency analysis – Milling machine.

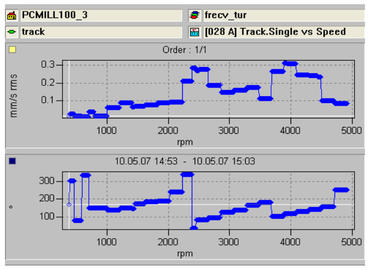

Fig. 11. Trend analysis – Milling machine.

Conclusions

By capturing dynamic measurements from operating machines such as vibration, electrical power, and dynamic pressure; it is possible to extract key component signature features. With this feature information, it is possible to tabulate specific metrics which drive plant maintenance and production schedules.

Component features are best extracted from sound and vibration signals when the appropriate signal analysis technique is used. By understanding the time-frequency characteristics of the raw signal, the algorithms that are most important can be identified.

R E F E R E N C E S

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