VIBRATION MONITORING SYSTEM OF A WIND TURBINE

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REZUMAT. Sunt bine cunoscute preocupările actuale în cadrul monitorizării şi diagnosticării turbinelor eoliene. Una dintre metodele de monitorizare folosită consta în măsurarea vibraţiilor în diferite puncte ale generatorului unei turbine eoliene şi urmărirea în timp a valorii intensităţii acestora. Lucrarea prezintă un sistem de monitorizare a vibraţiilor generatoarelor electrice folosind trei accelerometre piezoelectrice. Folosind un instrument virtual realizat în Labview, semnalele monitorizate sunt analizate folosind tehnica FFT de procesare a semnalului comparativ cu tehnica cepstrum.

Cuvinte cheie: vibraţii, FFT, Cepstrum, LabView.

ABSTRACT. Current concerns are well known in the monitoring and diagnosis of wind turbines. One of the monitoring technique used, consists of measuring vibration in different parts of a wind turbine generator and follow-up to their intensity value. This paper presents a vibration monitoring system using three piezoelectric accelerometers. Using a virtual instrument developed in Labview, monitored signals are analyzed using FFT signal processing technique compared with cepstrum technique.

Keywords: vibration, FFT, Cepstrum, LabView.

1. INTRODUCTION

In the field of monitoring there are different invasive and noninvasive methods for detection of early and permanent faults. Noninvasive methods are based on condition monitoring of the system by analyzing the information obtained from outside the equipment. In most cases, fault detection schemes and parameters used are specific to the monitored system. Fault detection methods can be classified into: methods based on signal analysis, model-based methods [1] and methods based on expert systems [2].

Vibration analysis is a method that provides the most of the information about the state of the generator and gearbox of a wind turbine [3].

This article presents a monitoring system of a wind turbine based on the measurement of vibration. Measuring the overall vibration level is straightforward, but unfortunately is useless in identifying the cause of high vibration. Unless the specific signature of a particular fault is known, there is no way to identify the source of vibration, without further analysis, because the overall system response is actually, at that point, the combined vibrations of all parts. All wind turbines contain a vibration sensor which is used only to detect strong vibrations that could endanger the turbine structure. These sensors are not intended to diagnose individual turbine components [4].

To identify the faults of individual components further analyzes of vibration signals acquired from the time domain sensors is needed. These signals are converted into frequency domain by means of Fast Fourier Transform (FFT) technique [5].

A study conducted in [23] showed the effectiveness of a vibration monitoring system of a wind turbine nacelle for rotor condition monitoring and fault prediction. The authors stated that, for constant speed wind energy converters, FFT algorithm can be applied directly to the measured acceleration signals in order to analize periodical nacelle oscillations.

In the literature there are many studies on vibration monitoring of rotating electrical machines, mostly focusing on bearing vibration monitoring using spectral analysis [6,7,8].

In [9] the author investigates the effectiveness of condition maintenance and predicted accurately bearing life based on vibration analysis.

In [19] the author analyzes the main aspects of the Vibration Analysis Technique associated with the Electrical Signatures Analysis Technique to accurately evaluate the operating condition of electrical equipments. Also the autor made a brief summary of major AC motor faults and their typical signatures (Fig.1).

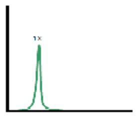
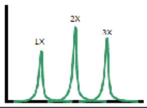
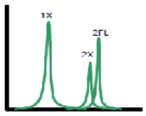
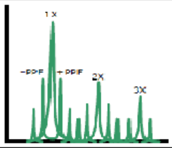
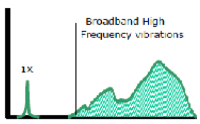
Mechanical faults	**Typical vibration pattern**	**Typical Spectrum**
Mass unbalance	1X	
Misalignment	2X, 3X	
Stator eccentricity	2XFL* *FL = Freq. line, e.g. 50/60 Hz	
Rotor eccentricity	PPF** sidebands around 1X, 2X, .. **PPF = Pole Pass Frequency	
Bearings wear	High freq. broadband vibrations	

Fig. 1: Vibration Diagnostic table for major AC motor faults [19]

2. FAST-FOURIER TRANSFORM (FFT) SPECTRUM ANALYSIS

All vibration measurements are made in time domain, which means that they reflect the changes in amplitude over time of speed and acceleration vibration. Another way of looking at the same information is to transform the time domain signal in the frequency domain so the frequency components of vibration signals can be identified. Vibration signals in time domain are transformed into frequency domain using FFT techniques. Acceleration waveform can be represented as:

$$a(t) = a_0 + a_1 sin\omega_1 t + a_2 sin\omega_2 t + \cdots \qquad (1)$$

where a_0, a_1, a_2, ..., are amplitudes frequencies ω_1, ω_2, … . Fourier amplitude spectrum *A(f)* corresponding to the signal frequency *f(t)* can be obtained as [10]:

$$A(f) = \int_{-\infty}^{\infty} a(t)\, e^{-j2\pi ift} dt \qquad (2)$$

By means of this analysis, a correlation of variations in the vibration signal and different faults of the equipment can be made[13].

In [15] the authors present an algorithm for early crack detection in a gear box using Fourier analysis of a signal acquired from a piezoelectric accelerometer.

Fourier transform, considers all systems as beeing linear and because of that all frequency spectrum is allocated to the linear part, thus neglecting the nonlinearities of any kind.

Practice has proved that real technical systems are nonlinear. Also practice has shown that experimental dynamic series are the sum of many components that can not be fully detected by a monospectral analysis, using only the Fourier transform [11,12].

There are some cases where it is not advisable to use spectral analysis for the analysis of vibration signals, as in the case of very low frequency signals acquired from shafts with low rotational speed. If a wind turbine main shaft rotate with 10...20 rpm and bearing characteristic defect frequency will be below 1 Hz ..

Given the very long period of sampling necessary to achieve the desired frequency resolution, FFT technique can be used in this case. But also other techniques ,such as Cepstrum, Wavelet, etc, can be used.

3. QUEFRENCY ANALYSIS

Cepstrum analysis, also called quefrency analysis, is FFT of the logarithm of a vibration spectrum. The name "Cepstrum" result from reversal of the first four letters of "spectrum". Independent variable on the x axis of the FFT is frequency. The independent variable of Cepstrum is called "quefrency", also the name resulted by replacing the first three letters of "frequency". Quefrency is a measure of time, but not in the time domain, this analysis revealing a periodicity of a spectrum.

Mathematically, Cepstrum is the result of taking the Inverse Fourier transform of the logarithm of the spectrum of a signal [18]:

$$c_x[n] = \frac{1}{2\pi} \int_{-\pi}^{\pi} log\left|X(e^{j\omega})\right| e^{j\omega n} d\omega \qquad (3)$$

Cepstrum analysis is particularly useful for detecting side bands in a frequency spectrum such as electrical machinery vibration spectrum, thus beeing possible detection of harmonics, caused by a faulty bearing, shafts related defects (cracks, misalignment and bending), blade and gearboxes related defects [16].

The power cepstrum provides the ability to detect the periodic signature in the spectrum at a single location with the well defined peak since it is the square of all the significant amplitude periodic peaks put together on a logarithmic scale.

The study conducted in [20] shows that the cepstrum analysis technique in the field of machinery fault diagnosis, using vibration signatures is superior and accurate compared to the frequency analysis technique, where sideband activity and harmonics are present. In this study vibration levels were recorded at two points on a bearing. The recorded data was analysed first using the spectral analysis techique and then cepstrum technique to identify series of harmonics in the spectrum.

4. VIBRATION MONITORING SYSTEM

Using techniques such as vibration analysis, by means of regular monitoring of operating parameters, wind generators faults can be detected early enough to allow for planning preventive mentenance, instead of making a reactive breakdown maintenance.

Measurement of vibrations at different points of wind electric generator and follow-up to their intensity value is a safe and effective measure to indicate the state of wear, and its evolution over time.

In the case of harmonic vibrations, with the instantaneous value of the vibration velocity:

$$v_i = \hat{v} * cos\omega_1 t \quad (4)$$

or of complex vibrations, i.e. a superposition of harmonic vibrations, vibration intensity is defined as the root mean square value (RMS value) of the oscillation velocity.

The RMS value is calculated from the time diagrams of the vibration velocity:

$$v_{eff} = \sqrt{\frac{1}{T}\int_0^T v^2(t)dt} \quad (5)$$

Acceleration, speed or displacement amplitudes ($\hat{a},\ \hat{v},\ \hat{s},\ j = 1,2,\dots n$) can be derived as functions of the rotating speed ω_1, ω_2,… ω_n. The measured value (the RMS value) was calculated according to ISO 2372 Standard, with the same formula [22]:

$$v_{eff} = \sqrt{\frac{1}{2}\left[\left(\frac{\hat{a}_1}{\omega_1}\right)^2 + \left(\frac{\hat{a}_2}{\omega_2}\right)^2 + \dots + \left(\frac{\hat{a}_n}{\omega_n}\right)^2\right]} = \sqrt{\frac{1}{2}(\hat{s}_1^2\omega_1^2 + \hat{s}_2^2\omega_2^2 + \dots + \hat{s}_n^2\omega_n^2)} = \sqrt{\frac{1}{2}(\hat{v}_1^2 + \hat{v}_2^2 + \dots + \hat{v}_n^2)} \quad (6)$$

If vibrations have not two slightly close frequency components which could generate beat phenomenon, the RMS value of the vibration velocity can be calculated as:

$$v_{eff} = \sqrt{\frac{1}{2}(\hat{v}_{max}^2 + \hat{v}_{min}^2)} \quad (7)$$

where:

$\hat{v}_{max}^2$: peak value at the maximum value of the envelope curve;

$\hat{v}_{min}^2$: peak value at the minimum value of the envelope curve;

If the RMS value is measured using a measurement device, the RMS velocity will be approximately:

$$v_{eff} = \sqrt{\frac{1}{2}(R_{max}^2 + R_{min}^2)} \quad (8)$$

where:

R_{max}^2: the maximum value indicated by the measuring device;

R_{min}^2: the minimum value indicated by the measuring device;

As the RMS value calculated according to (8) is not an accurate one, it is advisable to use this method only for very low beat frequencies.

The above analysis allows setting vibration velocity in the limits imposed in the standards. If the limits are exceeded, analysis of the vibration velocity vs. frequency, permit the fault identification on the electrical machine.

As shown in [21] positioning accelerometers has great importance in diagnosing equipment faults. This drawback can be overcome by using three accelerometers positioned at 120º.

If the measurements are performed using three accelerometers, the total vibration speed of the electric motor under diagnosis is calculated using the equation (9):

$$v_e = \sqrt{\hat{v}_{w1}^2 + \hat{v}_{w2}^2 + \hat{v}_{wn}^2} \quad (9)$$

the indices 1, 2 and 3 corresponding to the three accelerometers respectively.

Figure 2 shows the configuration of the proposed monitoring system. This system consists of three piezoelectric accelerometers MMF KD 35, with a sensitivity of 50 mV/g, three charge amplifiers, acquisition board from National Instruments PCI-6110 and a graphical interface.

The charge amplifier was designed using Altium Designer software and practical implementation is illustrated in Figure 3.

Amplified voltage signals are acquired with acquisition board PCI 6110 from National Instruments. This acquisition board has a sampling rate of minim1kS / s, has 4 analog inputs with a extended resolution of up to ± 42V.

Virtual instrument control panel used for monitoring and collecting data is presented in Figure 4 and in Figure 5 is the block diagram .

On this virtual instrument data acquisition specific parameters such as number of samples, sample rate and manner of the spectral analysis can be configured.

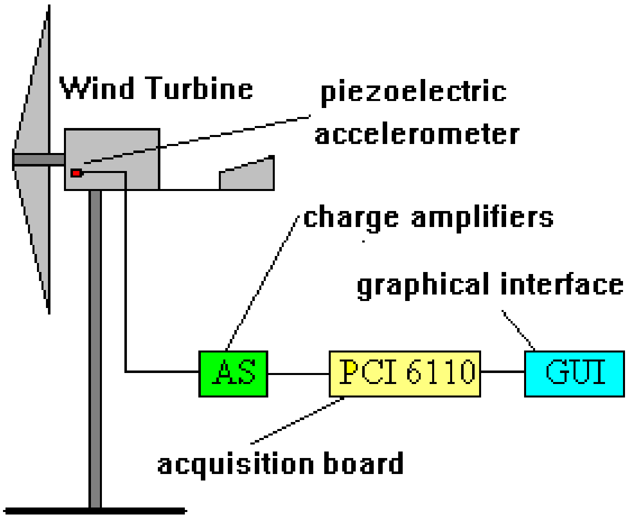


Fig.2. Vibration monitoring system.

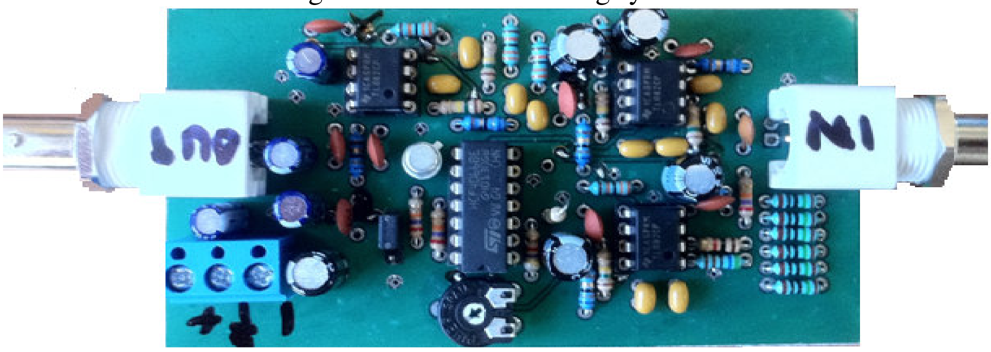


Fig.3 Charge Amplifier

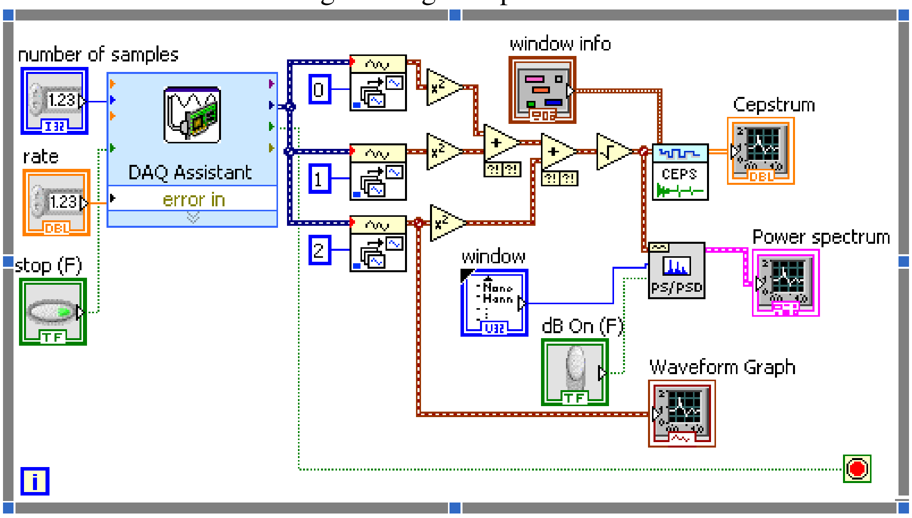


Fig. 4 VI Block Diagram

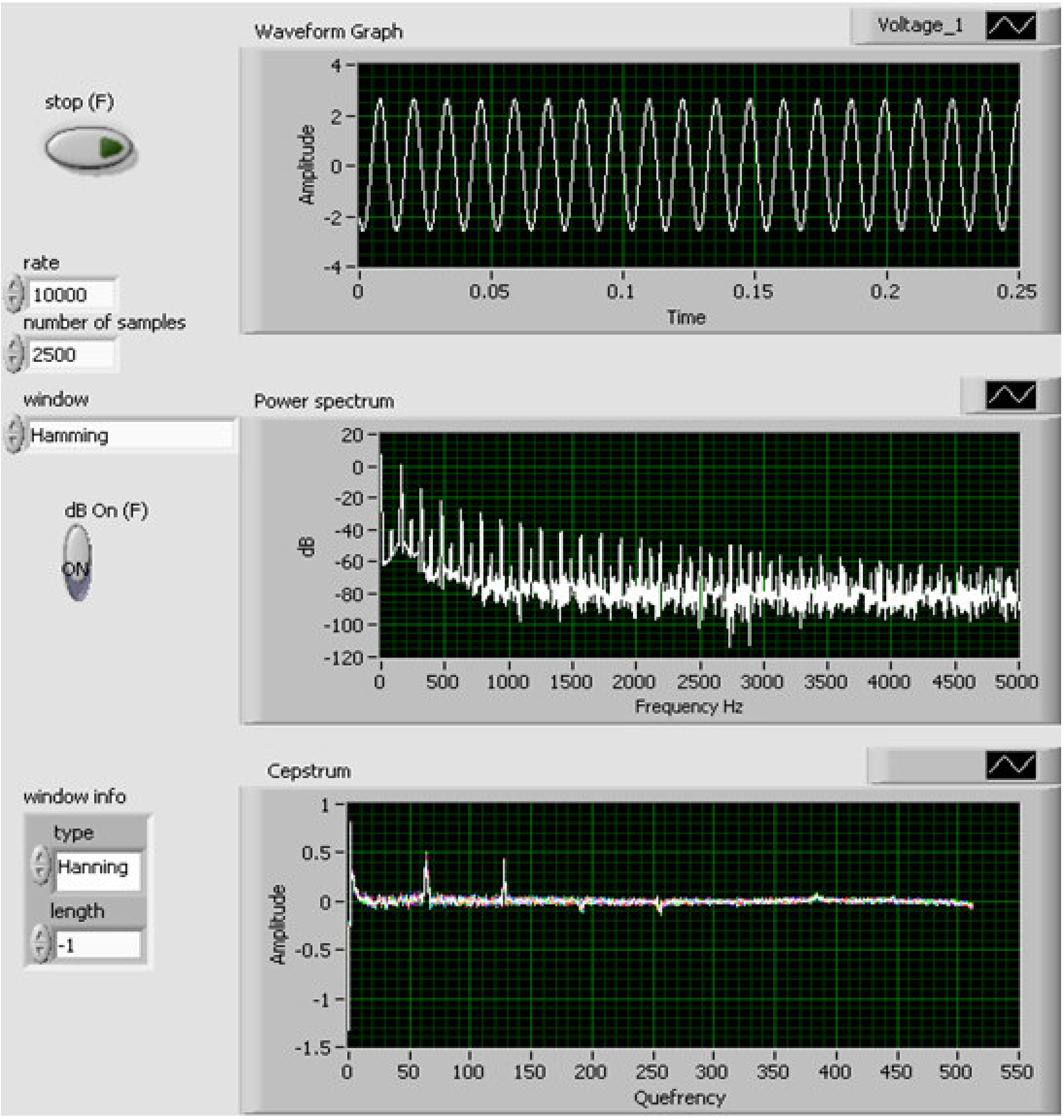


Fig.4 VI Front Panel

5. Conclusion

The vibrations signature analysis determined by the electric motors is a quite difficult task because in the real situations the shape of the amplitude vs. frequency characteristics (see Fig 4) is much more complex than the shape of the ideal ones (see Fig. 1), recommended in literature [19]. As can be seen in fig.4 cepstrum analysis provides a better resolution of the harmonics and peaks from the vibration spectrum.

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