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The Use of Spectral Windows in Analysis of Vibration Signals

Abstract. *Statistical spectral analysis of vibrations measured on moving elements of electrical machine with use of diagnostic information-measuring system was carried out. Special software was used in order to analyze the influence of spectral windows on the results of vibration diagnostics.*

Streszczenie. *Praca przedstawia system diagnostyczny maszyny elektrycznej oparty na statystycznej analizie spektralnej sygnałów rejestrowanych na ruchomych elementach maszyny. Główny nacisk położony jest na analizę wpływu rodzaju zastosowanej funkcji okna na wyniki analizy (**Zastosowanie okien spektralnych w analizie drgań**) .*

Keywords: vibration diagnostics, statistical methods, electrical machinery, information-measuring systems.
Słowa kluczowe: diagnostyka drgań maszyny elektrycznej, system pomiarowo-diagnostyczny

Introduction

One of the important phases of the process of diagnostics of moving parts of rotary electrical machines with usage of information-measuring systems (IMS) of vibration diagnostics is the processing of the measured informational signals aimed to increase the precision and reliability of the final results of diagnostics.

Problem formulation and the purpose of the paper

The purpose of this paper is the discussion of usage of spectral windows in the statistical spectral analysis of vibration signals measured from the moving parts of rotary electrical machines with usage of IMS of vibration diagnostics as well as investigation of the influence of such windows on the results of diagnostics.

Investigation of spectral windows influence on the results of vibration diagnostics

In order to obtain the experimental data for the analysis we used the laboratory model of the IMS of vibration diagnostics of moving parts of electrical machines [1] which includes the transmission of the measured signals by radio channel based on Bluetooth standard. As a result of measurements of the vibration signal from sensors with usage of digital IMS we obtain the realization of measured process in the form of time series – a number of time ordered samples.

Spectral windows are used to improve the spectral characteristics of sampled signals. It is well known that in case of time series of limited duration the Fourier transform produces spectral leakages caused by the discontinuity of input signal on its ends. Such leakages not only can to distort the shape of power spectrum, but also to hide the signals of low intensity. The application of spectral windows can minimize the leakages and therefore improve the results of diagnostics of electrical machines based on spectral analysis of its vibrations. This is due to the fact that the windowing of the signal in time domain leads to the modification of the signal shape in such a way that the starting and ending values became closer and therefore the break became smaller.

The software implemented in the main block of IMS allows performing of smoothing of the input signals with usage of different spectral windows. The shape and parameters of window to use are determined by the parameters of the input signal. According to the theory of spectral analysis, the signal has infinite duration. As no physical signal can meet that requirement, it is needed to represent the signal as an infinite sequence of repeats of the signal, shifted in time. These repeats are multiplied by a rectangular window which is equal to zero beyond the area of its definition. In case if the starting and ending values of the signal are the same, there is no discontinuity in such repeated signal. But in most of the real cases the beginning and ending points of the signal have different levels. The transition from such levels leads to a step in the signal's shape. Such steps cause the high-frequency components to appear in the spectrum of the signal while in the real signal those components are not present.

Application of windows in time domain should change the signal's shape in such a way that starting and ending values became closer minimizing the step in points of discontinuity [2]. Let's investigate the usage of different windows in the spectral analysis of the input signal. The investigated signal in time domain has the shape as it is shown on fig. 1.

Let's denote:

N – a width of the window in samples of discrete time. When *N* is odd number, window has a single maximum if it is not flat. If *N* is even number, it has maximum in 2 consecutive points.

n – integer in range $0 \le n \le N-1$.

1) Bartlett window (with zero-valued end-points) is described with the following equation:

$$(1)\qquad \omega(n) = \frac{2}{N-1}\cdot\left(\frac{N-1}{2} - \left|n - \frac{N-1}{2}\right|\right).$$

Let's apply the Bartlett window with duration of 10 s and discretization frequency of 1 kHz to the input signal by multiplying the signal's values by the window's values. As it is seen from the fig.2, due to the usage of window the discontinuity is significantly reduced. Power spectrum of the signal smoothed by Bartlett window is shown on fig.3.

2) Tukey window is defined as

$$(2)\quad \omega(n) = \begin{cases} \dfrac{1+\cos\pi\left(\dfrac{2n}{\alpha(N-1)} - 1\right)}{2}, & 0 \le n \le \dfrac{\alpha(N-1)}{2}; \\ 1, \quad \dfrac{\alpha(N-1)}{2} \le n \le (N-1)(1-\dfrac{\alpha}{2}); & \\ \dfrac{1+\cos\pi\left(\dfrac{2n}{\alpha(N-1)} - \dfrac{2}{\alpha} + 1\right)}{2}, & \text{otherwise.} \end{cases}$$

The Tukey window is composed of the fragments of cosine functions on the both ends. The value of α is equal to the ratio of the constant component of the window function to the cosine component. This coefficient changes between 0 and 1. If we choose $\alpha \le 0$, we would get rectangular window and for $\alpha > 1$ – Hann window [3].

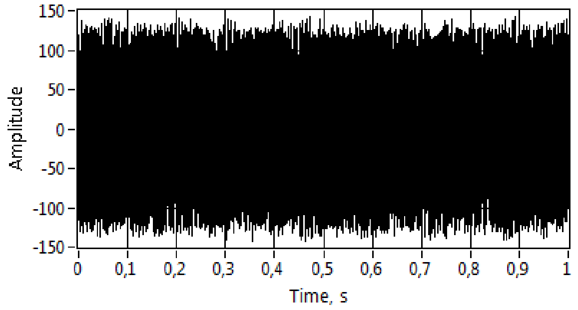

Fig.1. Time diagram of the measured signal

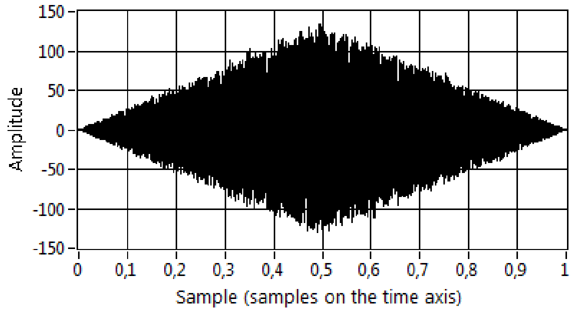

Fig.2. Diagram of the input signal smoothed with Bartlett window

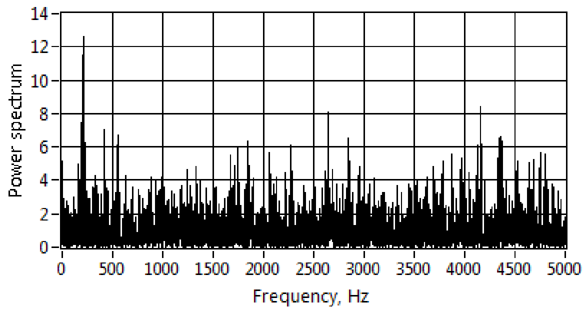

Fig.3. Power spectrum of signal smoothed with Bartlett window

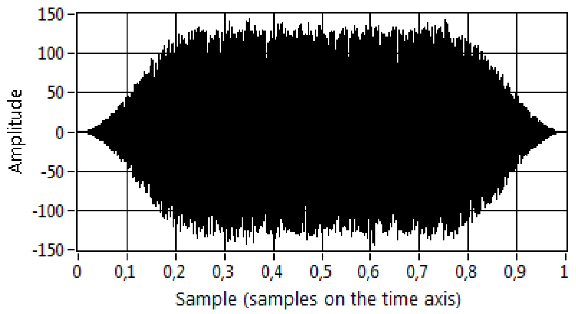

Fig.4. Diagram of the input signal smoothed with Tukey window

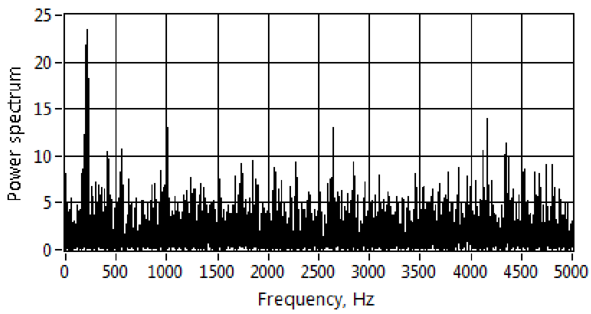

Fig.5. Power spectrum of signal smoothed with Tukey window

Let's apply Tukey window with duration of 10 s and discretization frequency of 1 kHz and $\alpha = 0{,}5$ to the signal by multiplying the signal's values by the window's values.

As it is seen from the fig.4, the discontinuity step is reduced as well.

The power spectrum of the signal smoothed by Tukey window is shown on the fig.5.

3) Parzen window is defined as

$$(3)\quad \omega(n) = \begin{cases} 1 - 6\left(\frac{|n|}{N/2}\right)^2 + 6\left(\frac{|n|}{N/2}\right)^3, 0 \le |n| \le (N-1)/4; \\ 2\left(1 - \frac{|n|}{N/2}\right)^3, (N-1)/4 < |n| \le (N-1)/2. \end{cases}$$

This window is a piecewise cubical approximation of Gaussian window.

Let's apply Parzen window with duration of 10 s and discretization frequency of 1 kHz to the input signal by multiplying the signal's values by the window's values.

Again we can see the reduction of the discontinuity on the fig.6.

The power spectrum of the signal smoothed by Parzen window is shown on the fig.7.

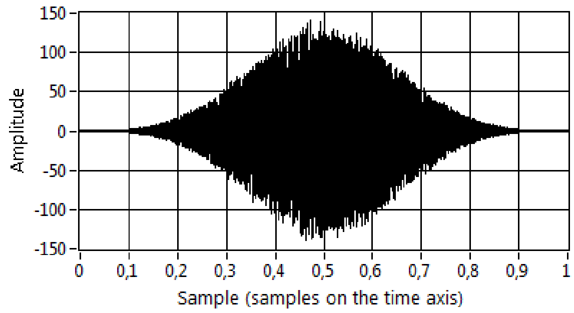

Fig.6. Diagram of the input signal smoothed with Parzen window

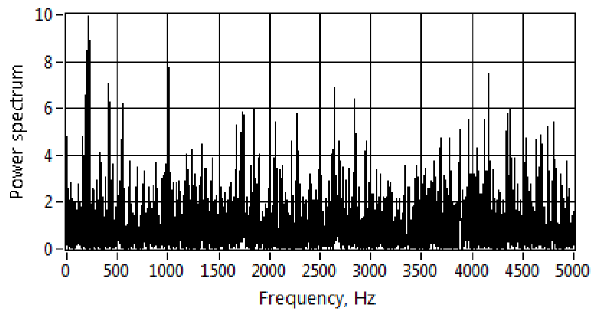

Fig.7. Power spectrum of signal smoothed with Parzen window

Let's analyze spectra of signals smoothed with different windows. For this purpose, select a frequency range and look on the scaled diagrams.

First, we should note that the results obtained with application of Bartlett and Parzen windows are very close. Comparing to the Rectangular window they provide significantly smaller width and smaller amplitude of spectrum values. The results of Tukey window application give a smaller width and bigger amplitude of spectrum comparing to the Rectangular window, but bigger values comparing to the Bartlett and Parzen windows.

Fig.9, fig.10 and fig.11 show comparison of power spectrum of the original signal (i.e. with application of Rectangular window) and power spectrum of the signal smoothed with Bartlett, Tukey and Parzen windows correspondingly.

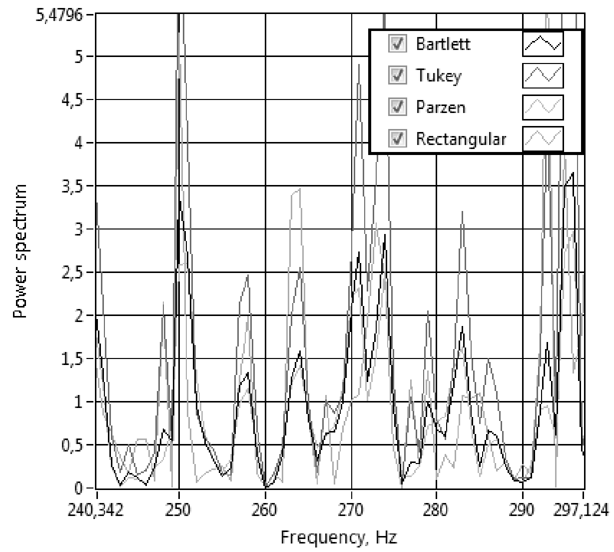

Fig.8. Comparison of power spectra estimated with usage of different windows

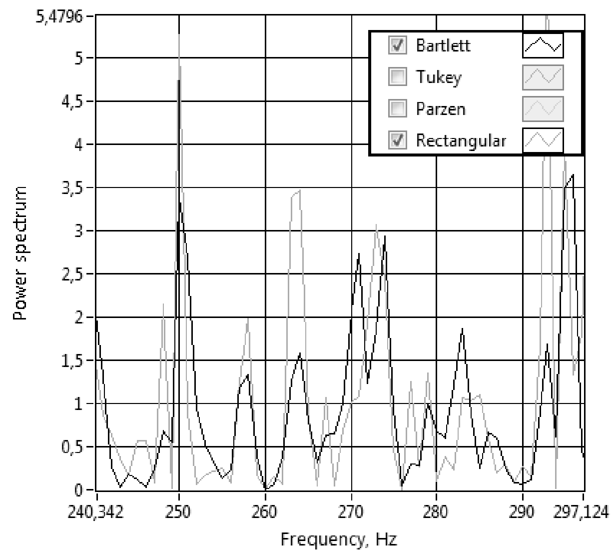

Fig.9. Comparison of power spectra estimated with usage of Bartlett window and Rectangular window

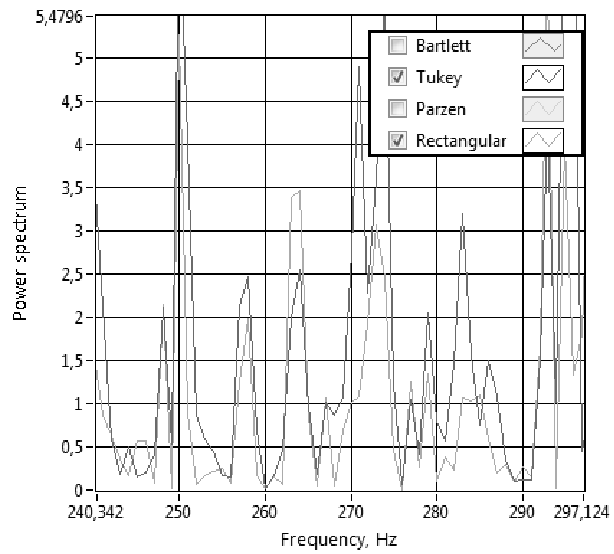

Fig.10. Comparison of power spectra estimated with usage of Tukey window and Rectangular window

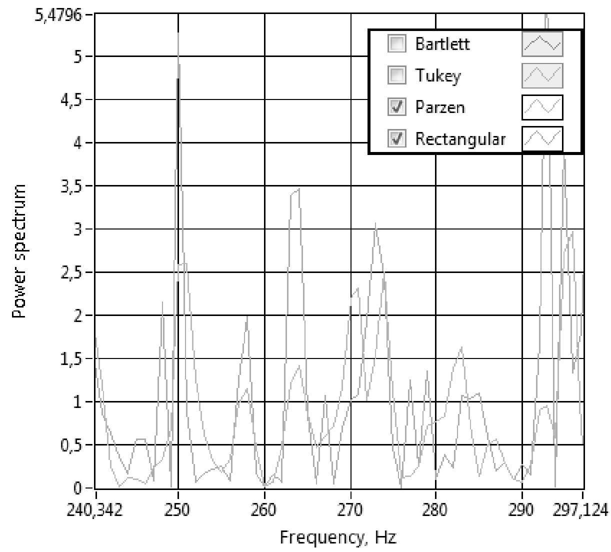

Fig.11. Comparison of power spectra estimated with usage of Parzen window and Rectangular window

From the analysis of the figures we can conclude that application of the windows gives better results because it minimizes the discontinuity step in the input signal and therefore reduces the spectral leakage. Therefore we can see on the diagrams the amplitudes of week frequency components which are lost due to the spectrum leakage if no window is applied.

Let's compute the dispersion of the signal smoothed with different windows:

a) Rectangular – 347,63;
b) Bartlett – 115,30;
c) Tukey – 238,96;
d) Parzen – 92,97.

So, the application of Parzen window gives the smallest dispersion of input signal and smaller amplitudes of frequency components in the power spectrum. Tukey window provides the biggest dispersion between the investigated windows, but also high amplitudes. Bartlett window has bigger dispersion than Parzen window, but better amplitudes. Thus the usage of Bartlett window in this case is preferable.

Conclusion

– the developed software which uses windows for smoothing of vibration signals for their spectral analysis provides better estimations of power spectra of the signals;
– for investigated vibration signals it is recommended to use Bartlett window; but this recommendation is not valid in case of arbitrary signals.

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