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The relationship between kurtosis- and envelope-based indexes for the diagnostic of rolling element bearings

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ABSTRACT

The coupling of kurtosis based-indexes and envelope analysis represents one of the most successful and widespread procedures for the diagnostics of incipient faults on rolling element bearings. Kurtosis-based indexes are often used to select the proper demodulation band for the application of envelope-based techniques. Kurtosis itself, in slightly different formulations, is applied for the prognostic and condition monitoring of rolling element bearings, as a standalone tool for a fast indication of the development of faults. This paper shows for the first time the strong analytical connection which holds for these two families of indexes. In particular, analytical identities are shown for the squared envelope spectrum (SES) and the kurtosis of the corresponding band-pass filtered analytic signal. In particular, it is demonstrated how the sum of the peaks in the SES corresponds to the raw 4th order moment. The analytical results show as well a link with an another signal processing technique: the cepstrum pre-whitening, recently used in bearing diagnostics. The analytical results are the basis for the discussion on an optimal indicator for the choice of the demodulation band, the ratio of cyclic content (RCC), which endows the kurtosis with selectivity in the cyclic frequency domain and whose performance is compared with more traditional kurtosis-based indicators such as the protrugram. A benchmark, performed on numerical simulations and experimental data coming from two different test-rigs, proves the superior effectiveness of such an indicator. Finally a short introduction to the potential offered by the newly proposed index in the field of prognostics is given in an additional experimental example. In particular the RCC is tested on experimental data collected on an endurance bearing test-rig, showing its ability to follow the development of the damage with a single numerical index.

1. Introduction

In many machine components, when damage occurs, a strongly impulsive signal is generated, triggering a series of vibrations according to the impulse response function of the structure of the mechanical system where the component is installed. This behavior is, for instance, typical of internal combustion engines [1], rolling element bearings [2], fluid instability phenomena in hydraulic and steam turbines [3–6] and rubbing phenomena in large turbomachineries [7,8].

Abbreviations: AS, autospectrum; BPFI, ball pass frequency inner; BPFO, ball pass frequency outer; CS2, second order cyclostationary; CPW, cepstrum pre-whitening; DFT, discrete Fourier transform; FFT, fast Fourier transform; IDFT, inverse discrete Fourier transform; IEPE, integrated electronics piezo-electric; IFFT, inverse fast Fourier transform; IIR, infinite impulse response; NSES, normalized squared envelope spectrum; RCC, ratio of cyclic content; RMS, root mean square; SE, squared envelope; SES, squared envelope spectrum

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In the last years, two main families of signal processing tools have gained a leading role in the diagnostic of such components: the kurtosis-based family and the CS2 family.

The first family consists of time and frequency domain indexes derived from the kurtosis index, which is chosen as a direct measure of the "impulsiveness" of the signal [10]. Kurtosis, band kurtosis, spectral kurtosis and kurtogram are the most used techniques belonging to this category. The spectral kurtosis, presented by Dwyer [11], has been indicated as a very effective tool for the identification of transients in a signal, representing, in the case of diagnostics, the response of the system to impulsive excitation due to the damage; however, the complexity of its calculation hindered its diffusion in industrial application. On the contrary, the kurtogram, introduced in this field by Antoni and Randall [12], has been further developed to ease its calculation in the so called Fast Kurtogram [13] and consequently represents an efficient tool to select the best band for the filtering step in the process of envelope analysis. Improved results have been shown for a higher-resolution kurtosis-based index, the protrugram, developed by Barszcz and JabŁoński [14]. This index is obtained by calculating the kurtosis of the analytic signal on a narrow band, which is shifted almost continuously along the frequency axis.

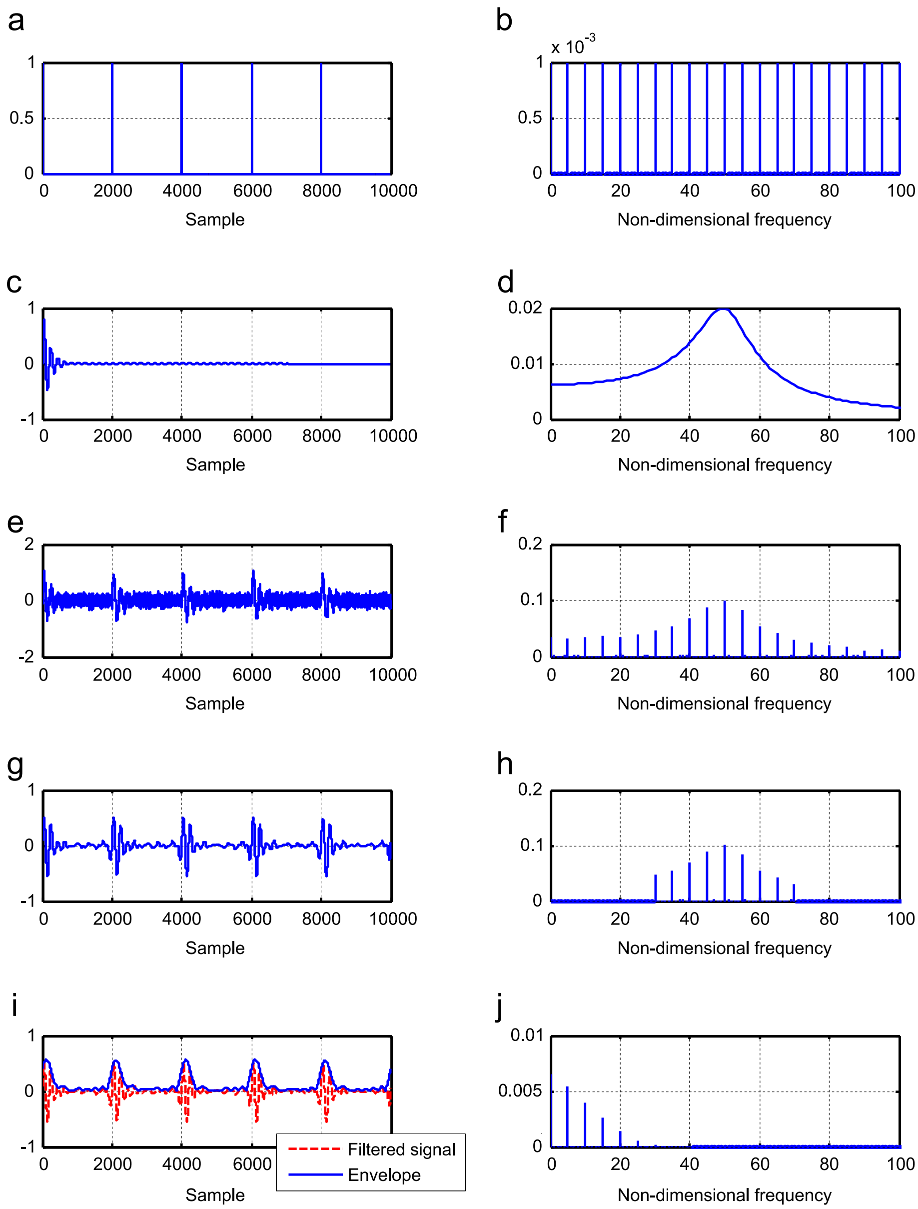

Fig. 1. Simulated signal of in case of an impulsive excitation on a 1 d.o.f. mechanical system: (a) impulse train in time domain, (b) impulse train in frequency domain, (c) impulse response of the system in time domain, (d) impulse response of the system in frequency domain, (e) simulated signal as convolution of impulse train and impulse response with additional white noise, (f) simulated signal in frequency domain, (g) filtered simulated signal in time domain, (h) filtered simulated signal in frequency domain, (i) envelope in time domain, and (j) SES.