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Normalization of vibration signals generated under highly varying speed and load with application to signal separation

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ABSTRACT

The paper presents a normalization dedicated to transform non-stationary vibration signals into signals characterized by purely stationary properties. For this purpose, a novel class of generalized periodic signals is defined followed by a proposition of a normalization technique, which takes advantage of available, instantaneous values of operational parameters. Within the paper, a well-known discrete-random separation (DRS) technique is recalled as an exemplary technique, which has been restricted to stationary signals so far. The authors present a step-by-step adoption of the DRS to non-stationary signals. The method is applied to simulated signal, test rig signal, and a vibration signal from industrial object. Additionally, for the purpose of synthesis of simulated signal, a new model of multi-component vibrations generated under varying regime is proposed. The presented method aims to expand existing solutions dealing with varying frequency to a more general solution dealing with independent, simultaneous varying frequency and amplitude of signal components.

1. Introduction

The fundamental role of the condition monitoring of machinery is to detect changes in technical state of the monitored object. When the change is detected, one can further investigate the state to assess the severity of the fault or to predict its future development. There is a huge literature for all these three major branches of research (see e.g. [1]). In early days of vibration-based condition monitoring fault detection methods assumed stationarity of operating conditions and used the relatively simple analysis in order to detect anomalies in the signal. The real world is much more complex and – strictly speaking – no machine can be assumed to work in stationary condition. Even if it operates in almost ideally stationary conditions, the machine needs to start and stop, though it is a trivial case. Apart from this, there are numerous groups of machinery for which non-stationarity is inherent [2]. To name only a few, there are wind turbines, mining machines, jet engines, car engines, etc.

The fundamental idea of any method of fault detection is to investigate the raw signal – or its transformation – e.g. frequency spectrum. Then select a part of the signal (e.g. a frequency band) and compare it with a reference value corresponding to "good" technical condition. The essential problem of condition monitoring under the varying operational

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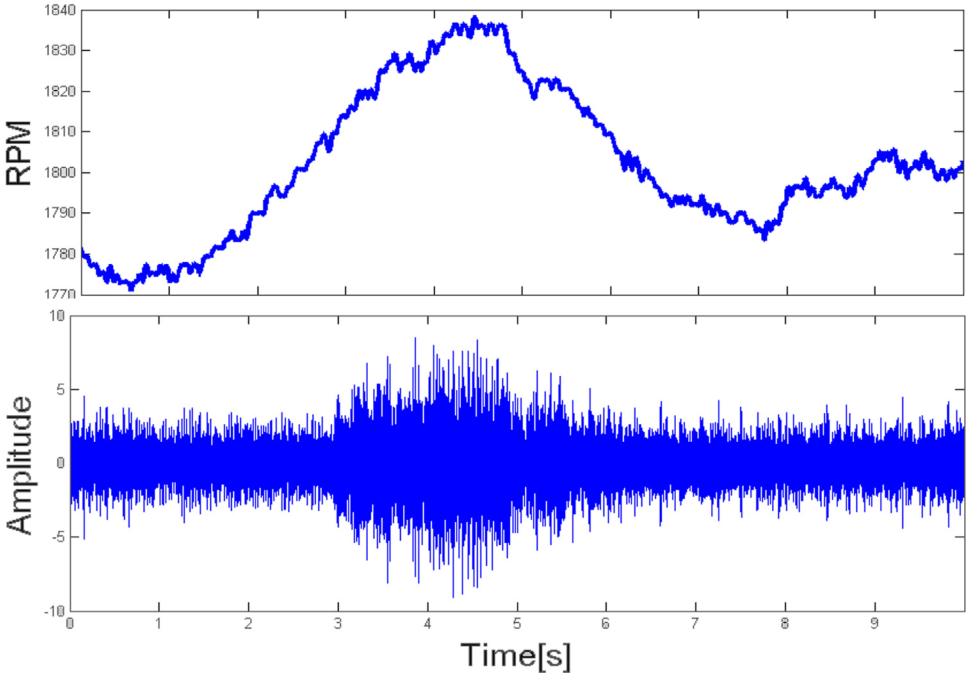

Fig. 1. Speed profile of the wind turbine (top) and corresponding vibration signal (bottom). A large change in the vibration signal is visible, but the technical state is obviously unchanged.

conditions is that the change in a condition, most often rotational speed or load, generates changes in vibration signals much higher than those which can be created by a machinery fault, especially in its early stage. The Fig. 1 presents an example of the speed change and the corresponding change in the vibration signal. Despite the significant change in the amplitude (and the frequency content, though invisible on the time plot) the technical state of machine is obviously unchanged.

The fundamental problem in the analysis of non-stationary vibration signals is to understand how varying operational parameters influence those signals. If this dependence is known, one can attempt to take it into account and possibly transform the vibrations signal, so it is operating-condition-independent and then compare scaled signals in order to find an informative change. The paper presents an attempt to build the model of vibration signals that include its varying operational parameters.

For many years, researchers tried to handle the problem of non-stationarity. Numerous methods were developed to allow the signal processing of non-stationary signals. For the purpose of this paper presented methods has been divided into few general subgroups:

– Time–frequency methods,
– Wavelets,
– Instantaneous frequency tracking,
– Empirical Mode Decomposition,
– Cyclostationarity.

In general, time–frequency representation of the signal allows to observe how instantaneous energy of the signal is distributed in both; time and frequency domain. There is a large variety of time–frequency analysis methods and they all have proven its usefulness in the field of non-stationary signals. Fundamental introduction to this approach can be found in [3] and [4] where basics of relatively large selection of methods are explained. Ref. [5] for a first time introduced the Instantaneous Power Spectrum (IPS) as a practical bi-domain representation of signal power. Although IPS was later used for real-life non-stationary signals analysis, due to relative complexity of the method itself it was quickly replaced by other methods, less demanding in the terms of computational power. More advanced time–frequency representations that base on the generalized concept of STFT can be found in [6,7]. For improved accuracy of representation in frequency domain adaptive short-time Fourier transform [6] can be used. It has been proven useful especially for components identification of nonstationary signals. The concept of generalized demodulation approach to time–frequency projections can be found in [8–10]. The one can notice that significant accuracy of representation of non-stationary signals in time–frequency plane can be obtained using presented approach. Another approach to time–frequency representation of the signals is Wigner–Ville distribution [8–11]. In discrete time, the Wigner-Ville spectrum is the discrete Fourier transform of the short-time