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Recent developments in vibration based diagnostics of gear and bearings used in belt conveyors

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Abstract. Local damage detection in bearings/gearboxes is one of the most intensively explored problems in condition monitoring literature. Also for mechanical systems used in mining industry this issue might be critical due to short time local overloading of surfaces in contact in gear-pair or bearings that often happens during operation. In general, the problem of local damage detection is well defined in literature, however, specific factors related to the mining industry, require adaptation of existing methods or even developing new approaches. In the paper, some of the most promising techniques with mining machinery context are briefly re-called. The key problems identified for mining machines are: operation under time-varying load/speed conditions, presence of time varying signal to noise ratio and non-Gaussian noise (impulses that appear incidentally, randomly, not with expected cycle or cyclically, however with different cycle related to another damage). All these situations motivated us to find novel solution. The paper might be considered as brief review of recent achievements in the field rather that comprehensive, holistic description of the problem.

Introduction

The conveyor belt of the conveyor is a very cost-demanding component involved in the framework of the whole transport system. This statement is confirmed by a fact that the high financial expenses are related not only with the purchase of a new conveyor belt, but also every process of the belt replacement requires an undesirable down-time of the given technology and in this way it causes the additional final loses [1]. The problem of local damage detection in rotating machinery (rolling element bearings, gears) is widely explored in the literature. One might say that it is well recognized [2-5]. Such an immediate impression is not really validated in practice. Practical implementation of techniques developed into laboratory conditions doesn't always lead to success for real machine in industrial operations. As it was suggested by Bartelmus [6], for proper diagnostics one should consider many aspects including design, operational conditions, degradation processes that occur in the machine etc. Contexts for mining machinery, helicopters, automotive systems, wind turbines, etc. are very different. Let us recall just a few examples from the mining world: bearing diagnostics in belt conveyor drive units is a complicated issue due to signal contamination coming from a gearbox located nearby [7-10], oil compressor valves produce massive impulses in a vibration signal that are difficult to distinguish from impulses coming from bearings damage [11], two different damages (different fault frequencies) might appear in a multistage gearbox, so they mask each other and it makes diagnostics difficult [12], both bearings and gearbox vibration-based analyses are difficult due to variability of load and speed that results in time varying properties of the signal and consequently signal-to-noise-ratio. Research team from Wroclaw University of Technology is focused on mining gears and bearings diagnostics for more than a decade. In the paper a synthesis of recent developments is provided.

Why mining machines are difficult to diagnose?

According to the McFadden's work from '80, damaged rolling element bearings should excite structural resonance and measured response appear as series of cyclic impulses [2,3]. Similarly for gearboxes, local damage will modify teeth pair stiffness and for constant speed periodic impulses caused amplitude/phase modulation of mesh frequencies should be easily detectable. Unfortunately, these models in mining machines require updating. Due to different factors depending on the machine, the observed vibration signal is complex. Mining machines operate under time-varying load/speed conditions, in presence of time varying signal to noise ratio and non-Gausian noise. It is very difficult to deal with such a noise, i.e. impulses that appear incidentally, randomly (not with expected cycle) or even in a cyclic way – cyclic impulses are associated to another local damage. All these situations motivates us to develop advanced techniques to overcome these problems. Due to lack of space, we will briefly recall them and refer to original already published works.

A generalized concept. As it was mentioned, vibration response from mining machine is usually complex due to design, operational factor and/or multiple faults appeared. It is very difficult to develop a model for such process. The basic idea is to use signal decomposition, namely to extract all sub-signals associated with a single source of vibration. Practically, simple filters, optimal/adaptive filters, time-frequency methods, especially wavelets, EMD, etc, are commonly used for vibration decomposition [4,5,7,13,14,20-22]. If there are several sources with cyclic behavior of the vibration, one might first identify them and in the second step extract source with given "alpha frequency" [12,15]. For the simplicity, in our research, signal decomposition via enhanced time frequency approach is used [15]. After the STFT-based decomposition one might play with each sub-signal (representing energy flow in a narrow frequency band) and analyze or model it. Signal modeling by means of stochastic processes (parametric modeling) and statistical approaches is very promising way of signal processing [4,8-12,15-17]. One of the most intuitive modeling approach is to apply periodically correlated processes, known in engineering community as cyclo-stationary analysis [12,15,17]. Especially for multiple faults, the Spectral Coherence Density map allows to identify frequency bands and fault frequencies that excite these bands. It might be used directly for diagnostics or it might be considered as a pre-processor for blind source extraction.

Signal separation or informative signal extraction is done using filtering of the raw vibration signal. Optimization or adaptation of the filtering procedure is based on maximization of kurtosis that is very sensitive to impulsive behavior of the signal (kurtogram, spectral kurtosis, MED, wavelet selection by maximization of kurtosis, etc.) [4,5,16,18]. In mining machines the kurtosis-based optimization often cannot be used due to presence of random, incidental impulses appearing in the vibration response. Recently, a set of novel criteria replacing kurtosis has been proposed. They are called selectors – because they are used for searching of spectral content with optimal signal to noise ratio and select these bands for further filtering [19].

It should be highlighted that there are also mixed approaches, that model and filter the data in the same time. It might be better to not search for pre-filtered vibration signal but search for information about local damage that is for example indirectly visible in filter coefficients variation [8-10].

Applications - Examples

In this section we present several examples to illustrate problems discussed above. In Fig. 1 one might easily notice the importance of processing. In the top subplot there is a raw vibration signal, while bottom one presents results of modeling using Schur filter coefficients [8-10]. Local increment of parameter provides information about presence of local damage. There is often a need to extract Signal of Interest, that has more physical meaning than filter coefficients. Till now, the most popular filter optimization procedures were based on kurtosis maximization. Fig. 2 shows results of such optimization for real vibration from a mining machine.

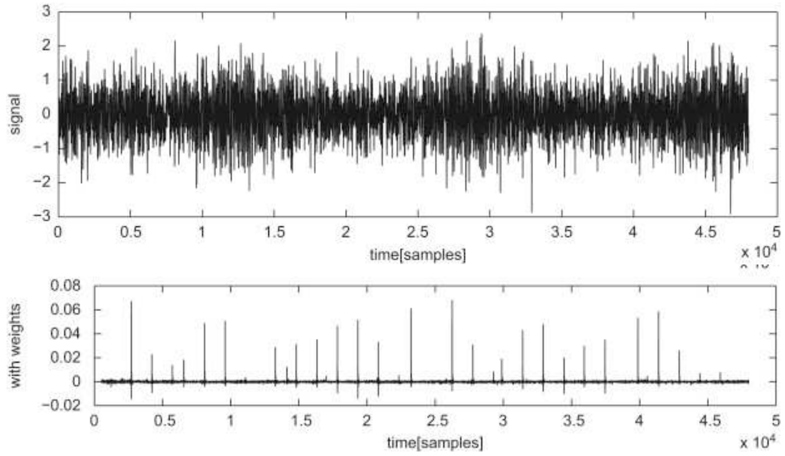

Fig. 1 Raw vibration signal (top panel) and results of modeling using a method based on Schur filter coefficients(bottom panel)

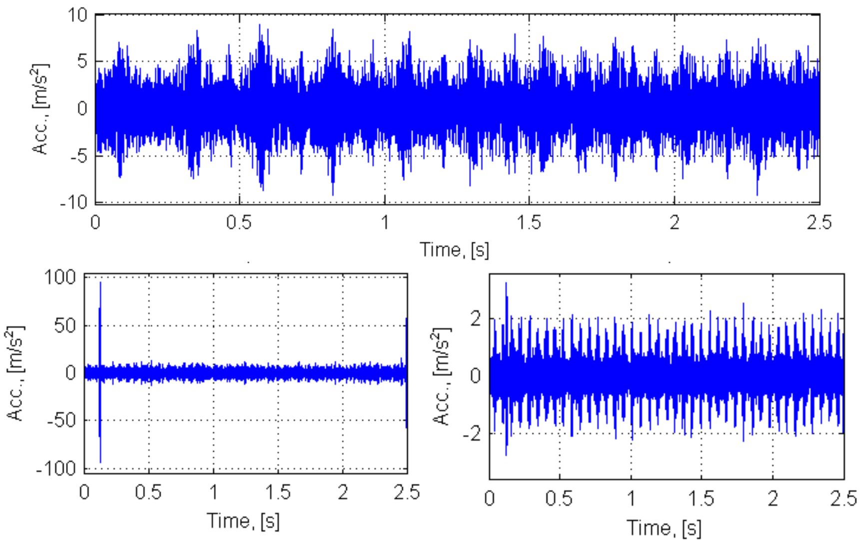

Fig. 2 Raw vibration signal (top panel), the AR-filtering-based residual signal after applying the filter based on the SK (bottom left panel), the AR-residual signal after applying the filter based on the average horizontal QQplot distance (bottom right panel)

It can be clearly seen that for the raw vibration (note AM modulation related to another than local damage problem) in the discussed data we have 3 important sources – one visible from raw signal related to improper operation of shaft 2 (c.a.4.1Hz), and completely hidden impulsive signals presented as results of filtering in bottom panels of Fig. 2. When applying kurtosis for filter design, the optimization procedure will converge to maximizing kurtosis value and extraction single, incidental impulse. Properly designed filter provide series of impulses associated with local damage (fault frequency 16.5Hz). There is asset of alternative criteria proposed in [19], for example it might be the Anderson Darling statistic.

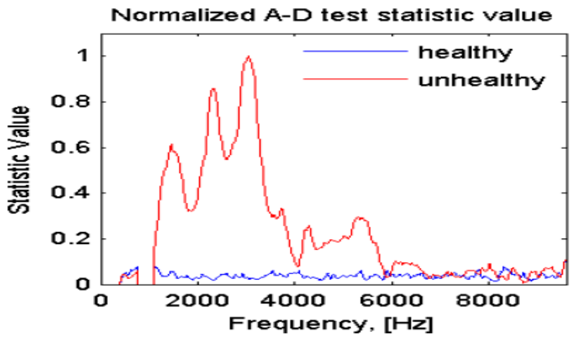

Fig. 3 Normalized values of A-D test statistic value-based selector for healthy and unhealthy signals

Finally, one might use more advanced techniques and visualization of data into two-dimensional plane. Fig. 4 (left panel) presents Spectral Coherence Density Map for signal containing two cyclic sources (two damage exist in the machine). Fig. 4 (center and right panels) show raw time frequency map and its enhancement proposed in [22]. Such enhancement extract information related to local damage in classic spectrogram when Signal of Interest is weak and masked by other sources - signal to noise ratio is really poor.

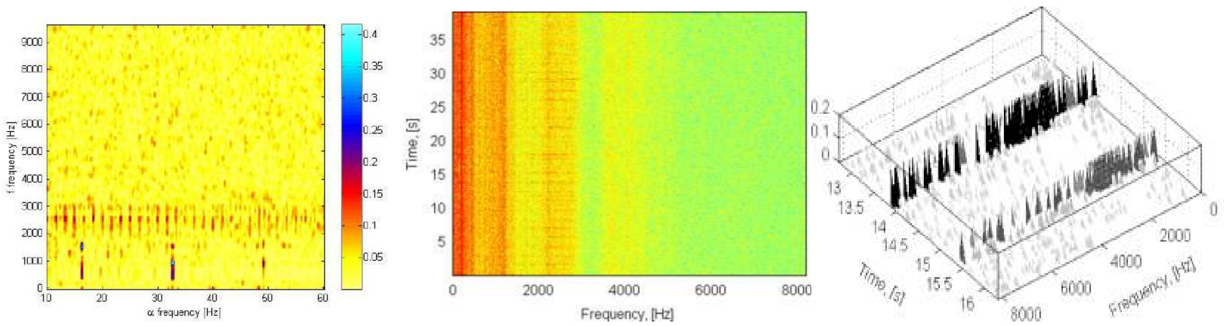

Fig. 4 Cyclo-stationary analysis of vibration from a three-stage gearbox with 2 damages (left panel), basic (center panel) and enhanced spectrogram (right panel)

Summary

In the paper several recent achievements in the field of local damage detection in mining mechanical systems have been discussed. The key problems identified in condition monitoring have been indicated. It was explained why classical, commonly used techniques cannot be used for condition monitoring of mining machines. To overcome mentioned problems, several novel techniques have been proposed. In some cases, they are adaptation of existing ones (i.e. spectral kurtosis based filtering has been modified by replacing kurtosis with other statistics). There also completely novel approaches developed for mining machines. It should be highlighted that all techniques have been tested for real data. Results presented in the paper illustrate procedures which come from real industrial conditions and harsh mining environment.

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