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SOME MODERN TIME FREQUENCY METHODS OF NOISE AND VIBRATION ANALYSIS APPLIED TO RAIL TRANSPORT

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Introduction

One of the central problems in measurements and analysis of noise and vibration since tram and railway traffic is the analysis of a time series.

Sampled signals obtained from sensors (accelerometers and microphone) may be used after analysis to develop of design criteria for improving the performance of the various elements of rail tracks and vehicles from aspect of vibration and noise. Analysis of complex vibrations and noise (especially rolling noise) normally takes the form of presentation of components frequencies related to their amplitudes, or a presentation of how the amplitude of specific signal varies with time.

Fourier methods have long been a standard tool, but recently much interest has been shown in extending the principals of Fourier analysis for the examination of non-stationary time series.

One particular extension of analysis techniques is the joint time frequency representations (TFR). TFR project the time series onto a joint two dimensional surface of both time and frequency. In representation the time series this way, a more useful presentation of the information contained in the time series may be achieved.

Discussion of basic theory

Fourier analysis is a time honoured method for determining the spectral information contained in analysis time series. One drawback of the technique of Fourier analysis is that it produces the time-averaged spectrum only. This is adequate only for a stationary time series, in which the statistical characteristics do not change with time.

In railway engineering the stationary series is often an unrealized idealization. The spectral content of the time series changes with time, and the time-averaged amplitudes found by the Fourier method is inadequate to describe such phenomena.

One technique of frequency analysis is popular non-parametric method developed by Welch. The Welch's method provides an optimal spectrum estimate pursuant overlapping block averaging time series by introduction two important modifications.

The Welch method can be complemented by more modern non-parametric techniques such as the Multitaper method (MTM), if need be the Multiple signal classification (MUSIC) or Eigenvector (EV) method.

The Multi-taper method provides an optimal spectrum estimate by minimizing spectral leakage while reducing the variance of the estimate by averaging orthogonal eigenspectrum estimates. The orthogonal tapers are discrete Slepian prolate spheroidal sequences (functions) as tapers on the windowed time series.

In order to estimate the spectral content of time series that is changing with time, one breaks the time series in smaller "short time" pieces by applying an a appropriate window function. Time series of each interval is assumed to be stationary and regular spectral analysis is performed on each piece in piecemeal. This method is known as the Short Time Fourier Transform (next STFT).

Short Time Fourier Transform is perhaps the most common TFR methods. It is simply the result of multiplying the time series by a short time window and performing a discrete Fourier transform. The action of this window is to localize in time, and the resulting spectrum is the local spectrum. This localizing window is then translated along the time axis to produce local spectra to as a spectrogram. One problem is, that the time resolution is the same for all spectral components. The estimation STFT is given by equation:

$$STFT_X^{(\omega)}(t',f) = \int_{-\infty}^{\infty} [x(t) \cdot g^*(t-t')] \cdot e^{-j2\pi f(t-t')} \cdot dt \,, \qquad (1)$$

where '*' denotes the complex conjugate, *g* is the short time window, *x(t)* is the signal, *t'* is the time location parameter, *f* is frequency and *t* is time.

One of the more recent attempts to localize the spectrum has been with the Wavelet transform. The basic philosophy is that any time series can be decomposed into a series of dilations and compressions of a mother denoted as $\psi(t)$. The wavelet transform of time data series is given by equation:

$$WT(\tau, s) = \frac{1}{\sqrt{|s|}} \cdot \int_{-\infty}^{\infty} x(t) \cdot \psi^{*}\left(\frac{t-\tau}{s}\right) \cdot dt\,, \qquad (2)$$

where *'*'* denotes the complex conjugate, *x(t)* is the signal, *t* is time, τ is translation factor, *s* is scale factor (frequency) and ψ is mother wavelet.

Wavelet transform gives a representation in the state space of the scale factor s *(or dilation) a and translation* τ*, but with the appropriate choice of wavelet* ψ*, it can be used to measure the power spectrum locally.*

The Wavelet transform is of particular interest for analysis of non-stationary and fast transient signals. The Wavelet transform provides an alternative to the classical Short Time Fourier Transform or Gabor transform and is more efficient than the Short Time Fourier Transform. Especially the Wavelet Transform is promising for acoustics and vibration works, since it offers constant percentage bandwidth resolution.

Laboratory measurements

To compare and test time, frequency and time-frequency analyses the method of reaction to mechanical shock was used. The reaction was measured on two different railway grates by the set with accelerometric detector Brüel&Kjaer, located on rail foot.

The first test grid was set together from concrete sleepers B91 with fastened rails of construction type UIC60 with flexible fastening VOSSLOH.

On Figures 1 (diagram left up) there are shown time-bound executions of immediate values of acceleration, measured by accelerometric detection elements. The frequency spectrum (non-smoothing) execution of the acceleration on the construction is shown on Fig. 1 diagram on the right up. On Fig. 1 diagram left down is shown the spectrogram, acquired from the time execution according Fig. 1 (diagram left up) using the Short Time Fourier Transform. On Fig. 1 diagram right down is subsequently shown the Wavelet transform.

The second test railway grid was than set together from wooden sleepers, on which rails of the construction size S49 were attached by means of classical rigid attachments through grilled key plate S4.

Similarly, on Figures 2 (diagram left up) there are shown time-bound executions of immediate values of acceleration, measured by accelerometric detection elements. The frequency spectrum (non-smoothing) execution of the acceleration on the construction is shown on Fig. 2 diagram on the right up. On Fig. 2 diagram left down is shown the spectrogram, acquired from the time execution according Fig. 2 (diagram left up) using the Short Time Fourier Transform. On Fig. 2 diagram right down is subsequently shown the Wavelet transform.

Conclusion

On the base of executed analyses of measured signals and by comparative of used methods of frequency and time-frequency analyses it is possible to form following conclusion:

- Methods of time-frequency analyses enlarge information about the given technical occurrence by stating the time localization of frequency components, i.e. they determine the size of power spectral density by appropriate frequencies at the given moment.
- From stated mathematical means of signal analysis it is suitable to use for time localization of occurrence of frequency of frequency components stationary and non-stationary signals of Short time Fourier transform, Wigner transform and Wavelet transform.
- The Short time Fourier transform is one of basic and as well fast proceeding of time-frequency analysis of signals. The accuracy and suitability of this method depends on choice of the window function, it's size and overlapping of particular segments. The application of method needs same experiences to define "reasonable" input parameters and interpretation of its spectrum as well.
- Wavelet transform is suitable mainly for analysis and reconstruction of different types of non-stationary signals, gained for example by measurements of noise, vibrations and stress. This transformation can find its use there, where classical methods of frequency analyses (i.e. Fourier transform) are not sufficient and where it is necessary to execute the frequency analysis time bound as well.
- Measurement and analysis of non-stationary signals with the use of time-frequency methods supplies a new view to transfer and non-stationary characteristics by the measurement of tram and railway constructions from the point of view of noise and vibrations.

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Resume

NĚKTERÉ MODERNÍ ČASOVĚ FREKVENČNÍ METODY ANALÝZY HLUKU A VIBRACÍ APLIKOVANÉ NA KOLEJOVOU DOPRAVU

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Tento příspěvek vysvětluje analýzu nestacionárních signálů s použitím okénkové Fourierovy transformace a transformace Wavelet. Obzvláště transformace Wavelet se jeví velmi nadějná pro analýzu zejména akustických a vibračních signálů.

Summary

SOME MODERN TIME FREQUENCY METHODS OF NOISE AND VIBRATION ANALYSIS APPLIED TO RAIL TRANSPORT

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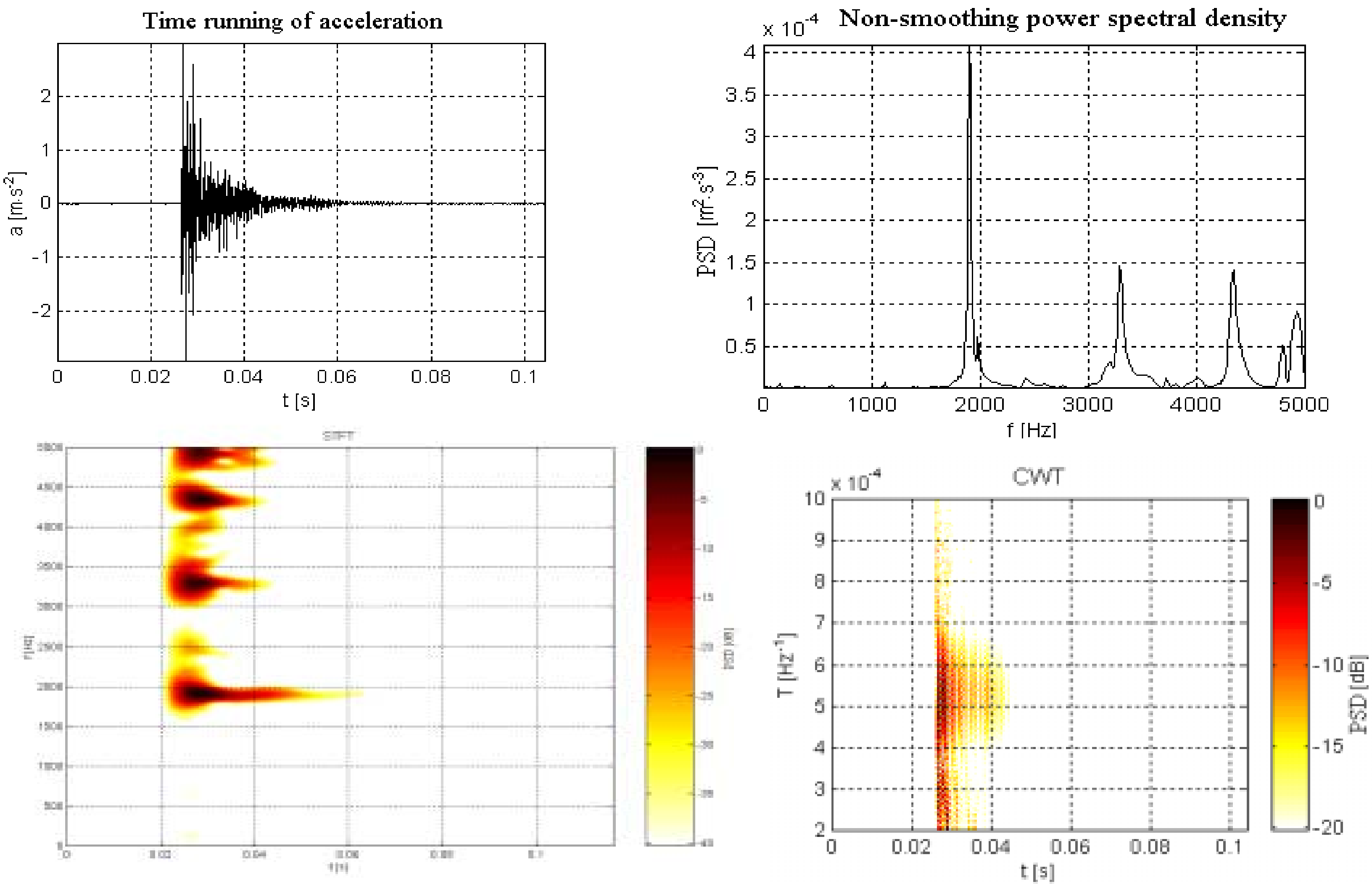
This paper examines analysis non-stationary signals using Short Time Fourier Transform and Wavelet Transform. These techniques yield an optimum resolution in both time and frequency domain simultaneously. Especially the Wavelet Transform is very promising for analysis of acoustic and vibration signals.

Zusammenfassung

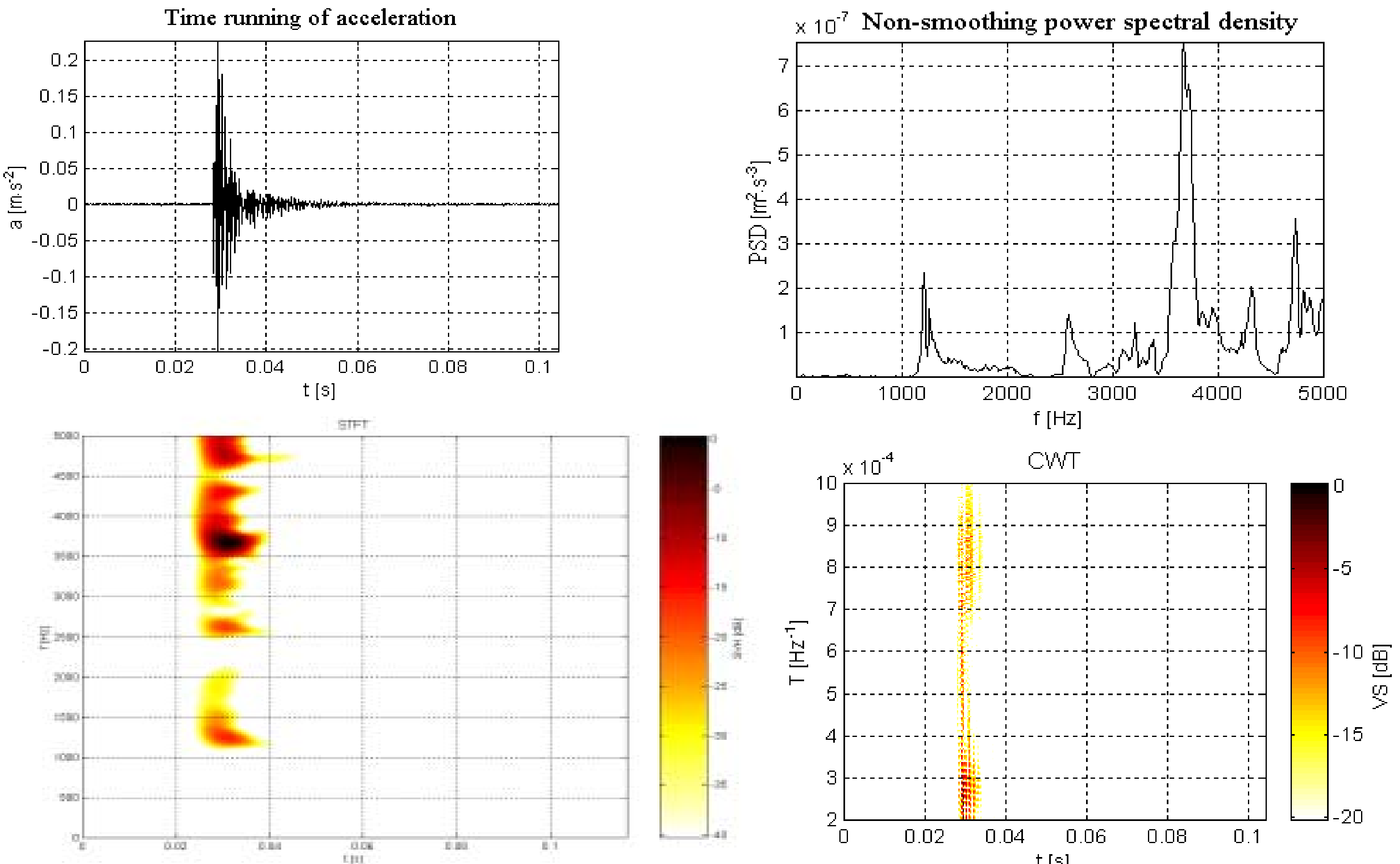
MANCHE MODERNEN FREQUENZ UND ZEIT-FREQUENZ TECHNIKEN ZUR ANALYSEN VON LÄRM UND VIBRATIONEN APPLIZIERT AN SCHIENENVERKEHR

Jaroslav SMUTNÝ

In dieser Beitrag ist die Analyse der nonstationären Signalen mit Verwendung der Fensterchen Fourier Transformation und Wavelet Tranformation erklärt. Insbesondere die Wavelet Transformation erscheint sich sehr zukunftsvoll für die Analysen namentlich der akustischen und Vibrationsignalen.



[1] ***Fig. 1*** *Time, frequency and time - frequency analysis on the first railway grid*



[2] ***Fig. 2*** *Time, frequency and time - frequency analysis on the second railway grid*