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**ANALYSIS OF SOME NOISE AND VIBRATION REDUCTION  
ACQUISITION ON URBAN TRAMWAY TRANSPORT BY USING  
FREQUENCY AND TIME-FREQUENCY TECHNIQUES**

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**Introduction**

An important share on the general exploration of noise and vibration has as well the tramway transport. There are a lot of noise and vibration sources. A contact of wheel and rail is one of important noise and vibration sources. The radiation of noise waves is tied close to vibration of structure. Therefore it appears as necessary to accompany noise measurements with measurements of vibration and oscillations. These measurements are important for determination sources and radiation.

Mechanical vibration and noise are dynamic phenomena, their intensity varies with time. The analysis of measured signal is complicated to determining their sources. Some modern technique times, frequency and time-frequency signal analyses are described in this article. The time-frequency techniques yield an optimum resolution in both time and frequency domain simultaneously. The Wavelet Transform is very promising for analysis of acoustic applications and the Short Time Fourier Transform for analysis of vibration measurement.

**Experimental set-up**

Two constructions of limitation of noise and vibration radiation were tested:

i) A new noise-free construction (rails TV 65, clip plate TR DIOR, wooden sleeper, open gravel ballast) was tested by using rubber side plates (Fig. 2) on the tramway track section

between stops Pisárky-Bráfova (Brno, Czech Republic). The execution of measured signal was by passages of Czech made tramways of types K2 and T3 of regular lines of the Transport Company of the town Brno. The noise microphone was located at the standard distance 7.5 m from the track axle in the level 1.2 m above the rail top.

ii) The T3 type tramway was fitted with "classical" design wheels, for the other, wheels with rubber dampers (Fig. 1) as designed by research staff of ŽDB (Iron Works and Wire Mills of Bohumín), wheel set plant. The superstructure was designed as follows: NP4 grooved rail on bearing plate, SB3 concrete sleepers, gravel on penetration macadam, asphalt topping. The noise microphone was located at the minimum spacing from contact of wheel and rail.

The noise gauge Investigator 2260 from the company Brüel & Kjaer was used for noise measurements and an adapted apparatus from the same company was used for the measurement of vibrations. The noise level  $L_{eq}$  was chosen for noise analysis by application of third-octave spectrum. Some modern methods, as Fourier transformation, Short Time Fourier transformation or Wavelet transformation, were used on measured vibration signals.

### Time-frequency analysis

A modern time-frequency technique – Short Time Fourier Transformation – was chosen for presentation some analysis of non-stationary real signals. The idea of the Short Time Fourier Transform (STFT) is to split non-stationary signal into fractions within which stationary assumptions apply and to carry out a Fourier transform on each of these fractions. Note that the length and shape of the window, and also its translation steps, are fixed. These choices have to be made before starting the analysis. STFT provides constant absolute bandwidth analysis, which is often preferred for vibration signals in order to identify harmonic components. STFT offers constant resolution in time as well as in the frequency domain, irrespective of the actual frequency. This transformation is mathematically defined

$$STFT(\tau, f) = \int_{-\infty}^{\infty} [s(t) \cdot g^*(t - \tau)] e^{-j2\pi f(t - \tau)} \cdot dt,$$

where  $s(t)$  is analyzed signal,  $g(t - \tau)$  window,  $t$  time,  $f$  frequency,  $\tau$  time localization and  $j$  imaginary symbol.

In the two dimensional time-frequency joint representation, the vertical stripes of the complex valued STFT coefficients  $STFT(t, f)$  correspond to the Fourier spectra of the windowed signal with the window shifted to given times  $t$ . If one takes the square modulus of the STFT, vertical stripes of the time-frequency joint representation are the spectral powers of the quasi-stationary segments of the signal and are referred to as the spectrogram.

The analysis of non-stationary signals using Short Time Fourier Transform may provide new insight into the transient and non-stationary characteristic of tram and rail constructions from view vibration and noise.

### Experimental results

There are results of the noise and vibration tests on the tramline with and without rubber side plate. The third-octave spectrum of noise level  $L_{eq}$  of the tram K2 passage over these constructions shows lower noise level on tram with rubber (Fig. 3). Maximal reduce of noise (15 dB) was on frequency from 250 Hz to 1250 Hz. All measured noise levels ( $L_{Aeq}$ ,  $L_5$ ,  $L_{50}$  and  $L_{90}$ ) were preferable for noise-protection structure (Fig. 4). There are shown time-

bound executions of immediate values of acceleration on Fig. 5 and Fig. 7. We can judge from the comparison of time-bound courses of noise-protection tramline (Fig. 7) and conventional tramline (Fig. 5):

i) immediate values of acceleration are by the construction without the noise-protection nearly by 100 % higher than by the construction with noise-protection

ii) distinguishing of individual axes approaching the measured point of the rail is remarkably more perceptible by the construction with noise-protection due to the higher damping of the measured signal.

The spectrograms, acquired from the time execution according to Figs. 5 and 7 using the Short Time Fourier Transform are shown on Figs. 6 and 8. This method is very suitable for the elaboration of non-stationary signals. It makes it possible to localise the signal both in time, and in frequency regions. From the reason of more objective representation the more suitable time and frequency section was used. On it there is to be seen very distinctive time layout of important frequency elements of signal measured in the given time interval.

The tests of tram T3 with and without rubber damper wheels show on Fig. 9, 10 and 11. A drop in noise level for new design wheels is evident for the microphone being located at the wheel-to-rail contact point (Fig. 9) where the noise levels are substantially lower (in a range of 6 to 8 dB). The vibration frequency response plots show the characteristic frequencies to be approximately the same for the old design (with no damper; Fig. 10) and for the new design (with rubber damper; Fig. 11). In the frequency ranges from about 500 to 700 Hz and from 1400 to 1700 Hz, the power spectral density is seen to drop to about one half of that generated by the old design wheel. Fig. 10 (upper chart) shows the acceleration versus time plot for the old wheel design and Fig. 11 (upper chart) shows the same quantity for the new wheel design (with rubber damper), as measured by the accelerometer. Fig. 10 (bottom chart) shows the occurrence of frequency components of the power spectral density for the old design and Fig. 11 (bottom chart) shows the same quantity for the new design (with rubber damper). These diagrams show again that from the viewpoint of the maximum acceleration as well as the magnitude and distribution of the power spectral density frequency components the new design wheel (with rubber damper) is more advantageous.

### Conclusion

The measurements and the following evaluations show that the use of side plates, bound to the flexible fastening it would be possible to reduce considerably the level of noise and of vibration in the neighbouring environment. Even when measurements were executed on the tram track, it is possible on the basis of reached results and analyses to suppose that it will come to similar reduction of rolling noise on railway tracks as well. Those conclusions are however to be supported by further complex measurements not only of rail subbase and rail superstructure, but by complex analyses of train units and on different points of tramway and railway tracks. In the end it is necessary to claim, that to a qualitative treatment of measured data some by us not commonly used means of time-frequency signal analyses contributed.

The results presented above show that the new design wheels (with rubber damper) lead to more favourable noise characteristics than the former design wheels. The noise characteristics are particularly more favourable in the frequency range from 500 Hz to 2 kHz. It may be stated that the typical values of the power spectral density at characteristic frequencies of rail vibrations are also more favourable for the new design (with rubber damper) as compared with the old design wheels.

### References

- [1] Pazdera L., Smutný J.: *Measurement and Analysis the Tram Wheel with Noise and Vibration Insulating Measures*, International Conference, New Requirements for Materials and Structures, September 29-30, 1998, Prague, pp. 319-324, ISBN 80-01-01838-5.
- [2] Pazdera L., Smutný J.: *Measurement and Analysis the Construction of Tram Superstructure with Sound and Vibration Insulating Measures*, International Conference, New Requirements for Materials and Structures, September 29-30, 1998, Prague, pp. 315-318, ISBN 80-01-01838-5.
- [3] Smutný J., Pazdera L.: *Some Methods of Reducing Noise and Vibration from Urban Tramway Transport*, The 7<sup>th</sup> International Scientific Conference, MOBILITA 98, Bratislava, Slovakia, September 3-4, 1998, pp. 332-337, ISBN 80-227-1092-X.
- [4] Pazdera L., Smutný J.: *Time-frequency analysis of mechanical quantities employing wavelet transformation*, 36. EAN, Košice, Acta Mechanica Slovaca, 1998, pp. 227-230, ISSN 1335-2393.
- [5] Pazdera L.: *Wavelet Analysis - Modern Tool to Description of Acoustic Emission Signals*, Proceedings of International Workshop, Research Activities of Physical Departments of Civil Engineering Faculties in the Czech and Slovak Republics, Liškovec, July 25-26, 1998, pp. 63-64, ISBN 80-214-1144-9.

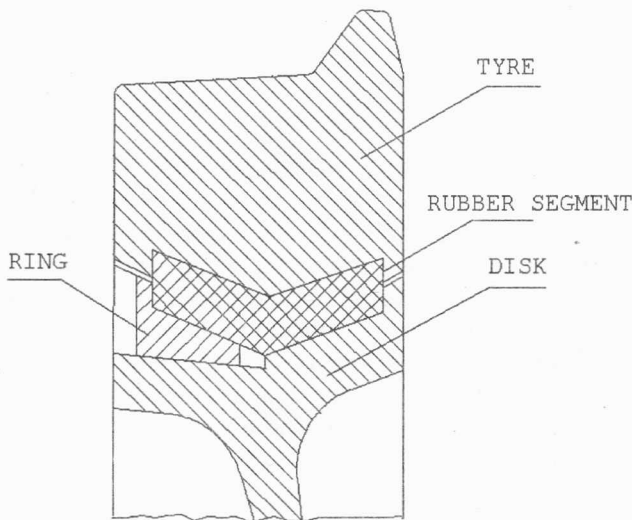
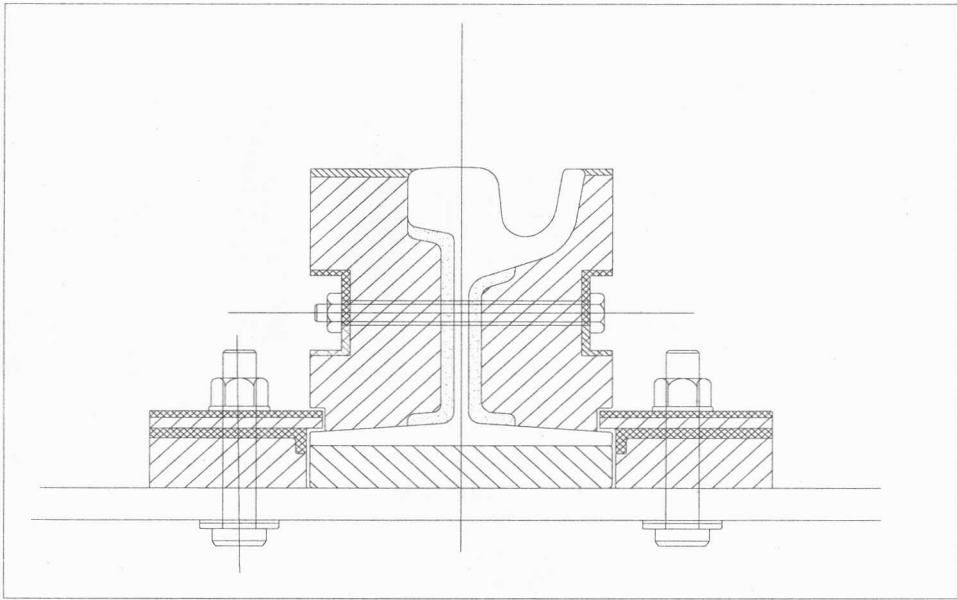
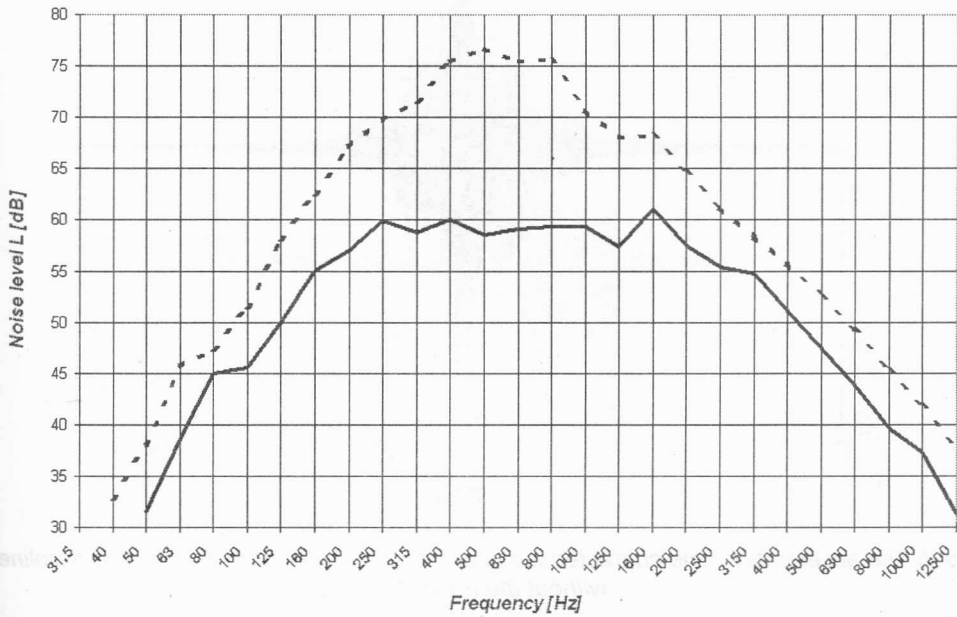


Fig. 1 Rubber damper wheel design



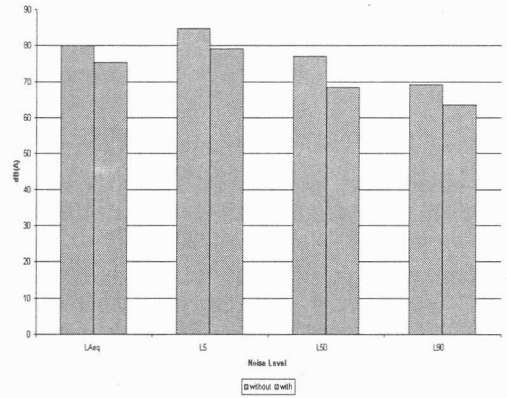
**Fig. 2** Rubber side plates



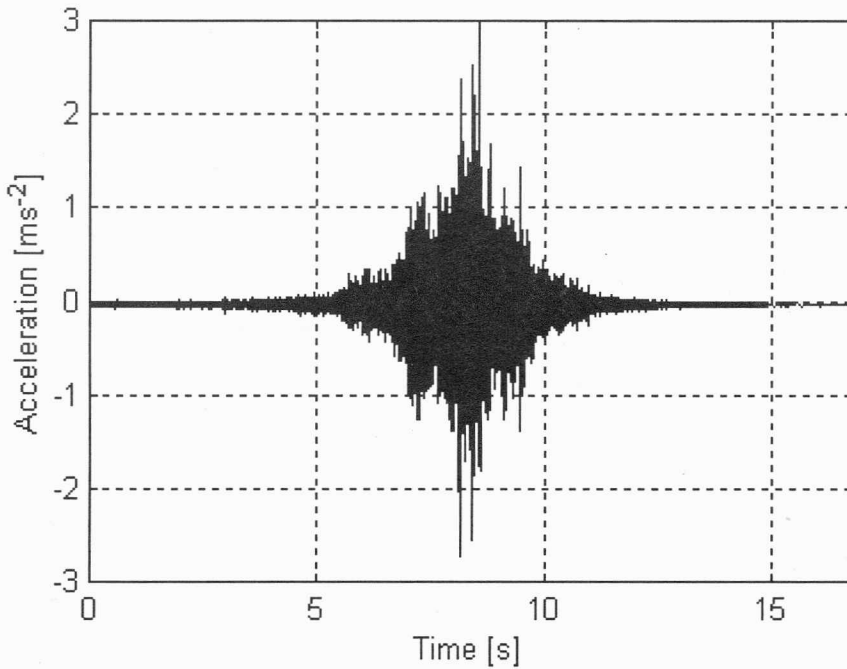
**Fig. 3** The equivalent noise level dependent on frequency (third-octave characteristic) of the tram passage over the construction without (---) and with (—) noise-protection

Noise Level	Noise-Protection	
	without [dB(A)]	with [dB(A)]
$L_{Aeq}$	80,1	75,4
$L_5$	84,8	79,2
$L_{50}$	77,1	68,5
$L_{90}$	69,1	63,5

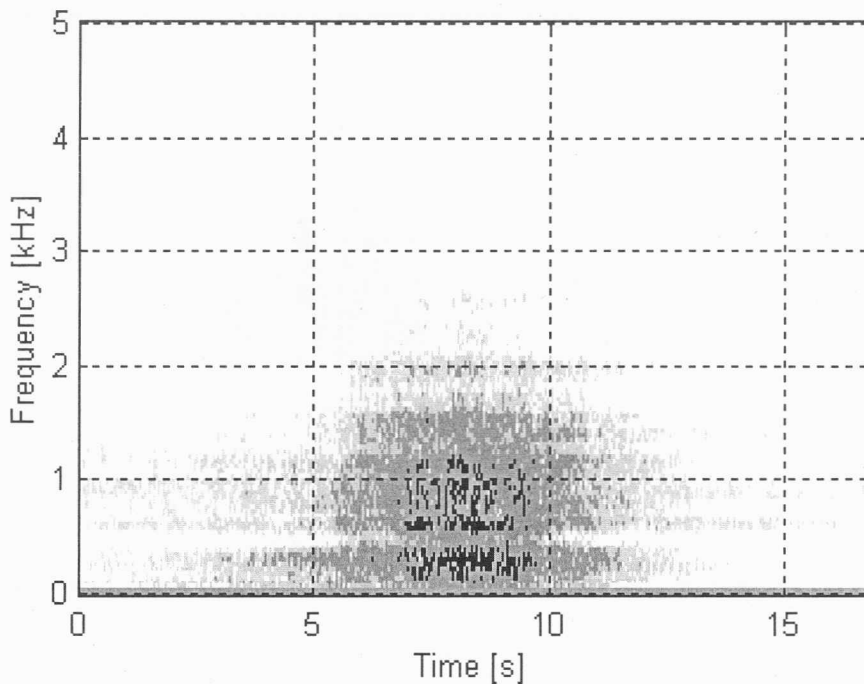
$L_{Aeq}$  – equivalent noise level  
 $L_5, L_{50}, L_{90}$  – statistic noise level



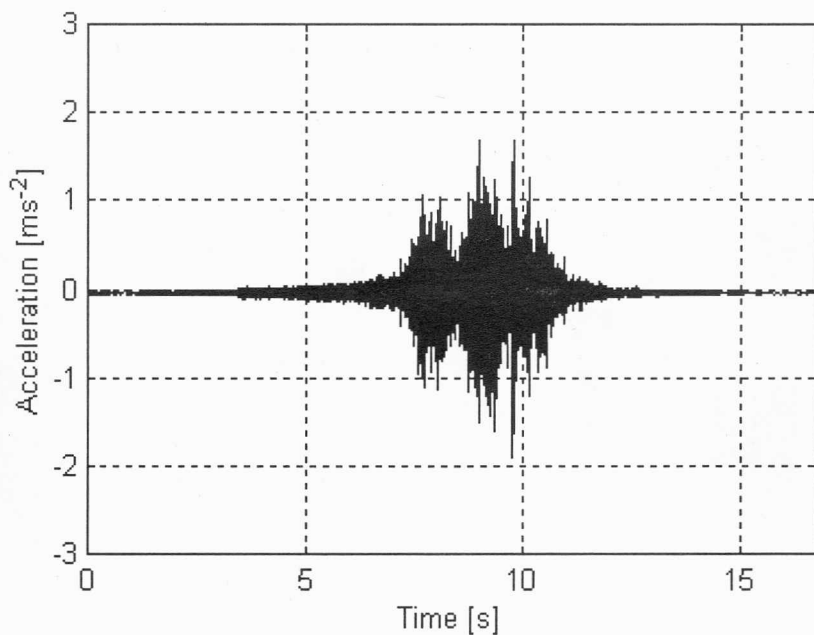
**Fig. 4** Noise level of the passage of tram K2 over the tramline with and without noise protection



**Fig. 5** The acceleration time characterisation of the passage of tram K2 over the tramline without the noise-protection.



*Fig. 6 Short Time Fourier Transformation of Fig. 5.*



*Fig. 7 The acceleration time characterisation of the passage of tram K2 over the tramline with the noise-protection.*

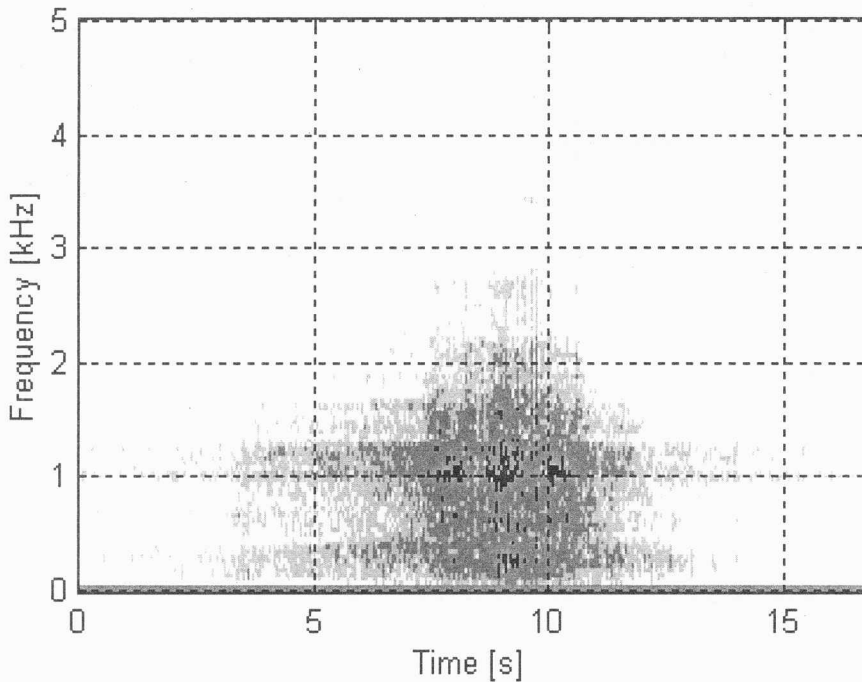


Fig. 8 Short Time Fourier Transformation of Fig. 7.

Speed 40 km/h, Microphone near wheel

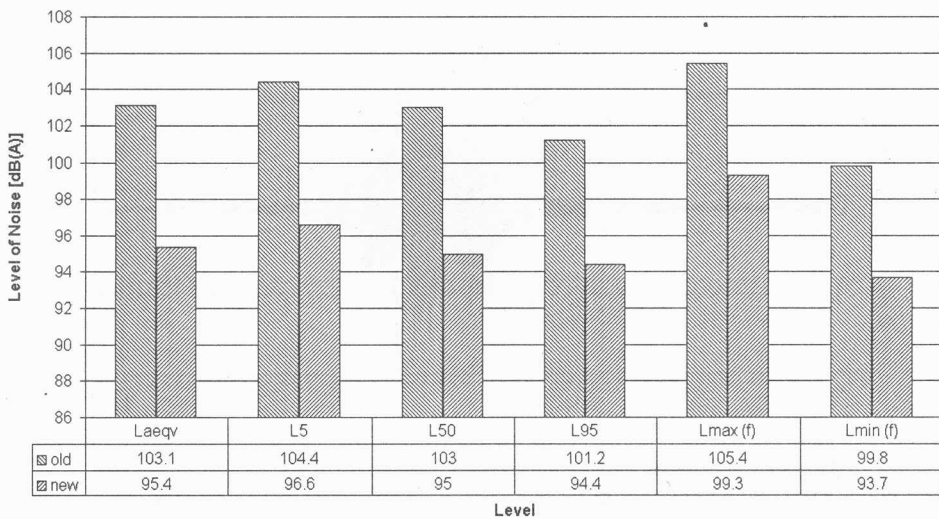
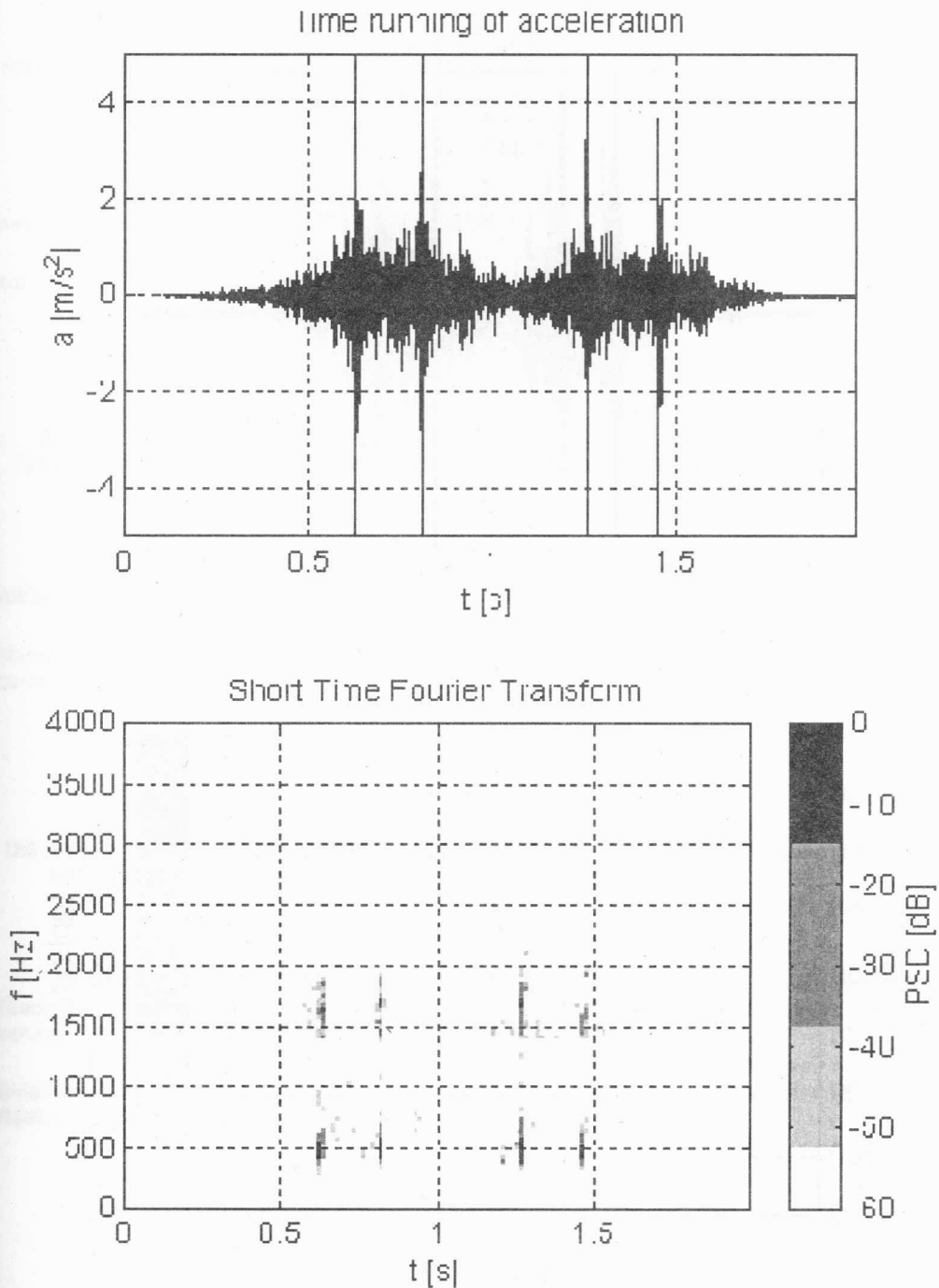
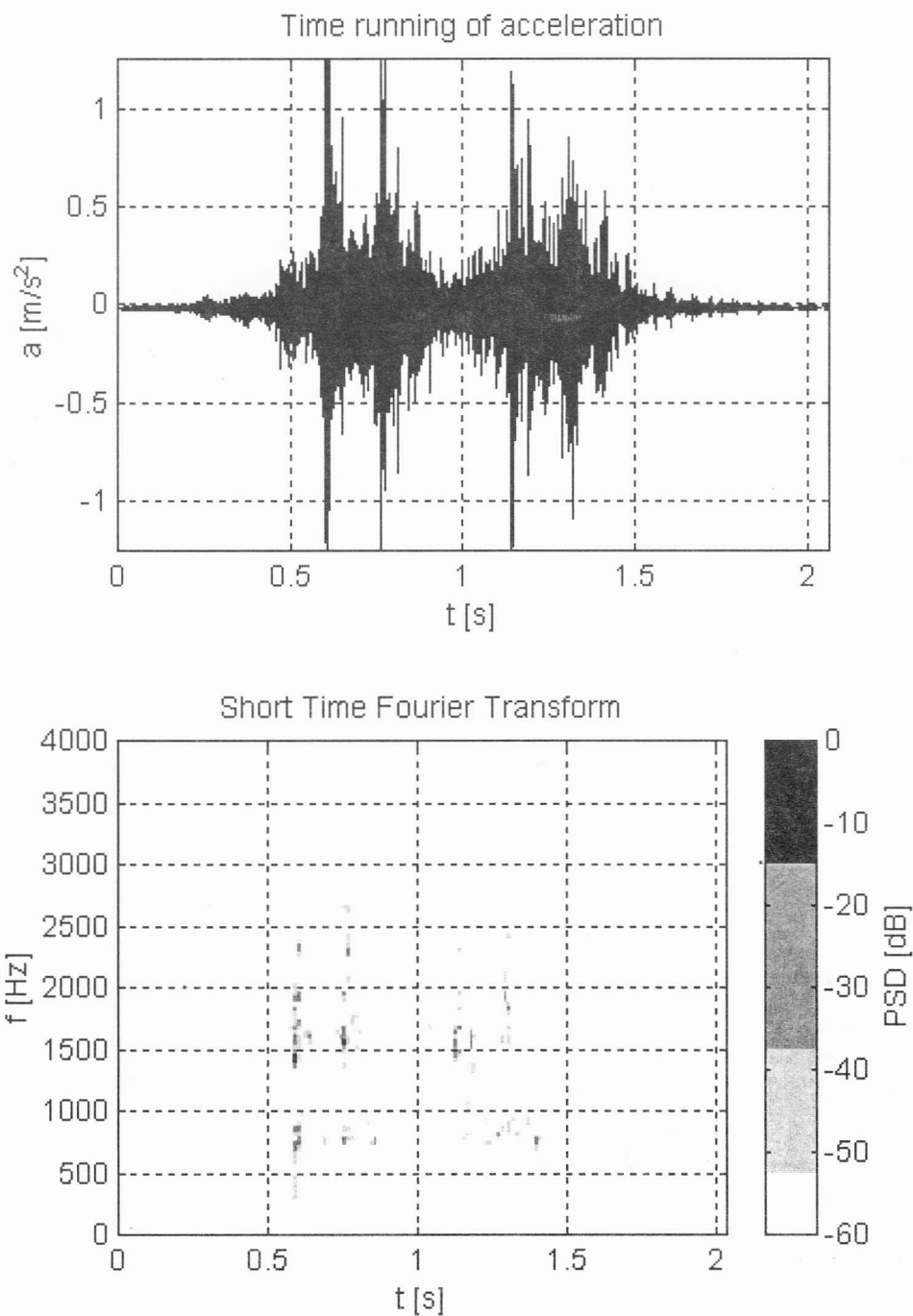


Fig. 9 Comparison of noise levels as measured by the microphone being fitted in a fixture at the new and original design wheel (speed,  $40 \text{ km} \cdot \text{h}^{-1}$ )



**Fig. 10** Acceleration versus time plot, FFT, old design of wheels.



**Fig. 11** Acceleration versus time plot, FFT, new design of wheel.

## Resumé

### **ANALÝZA PROTIHLUKOVÝCH A PROTIVIBRAČNÍCH OPATŘENÍ U TRAMVAJOVÉ DOPRAVY S VYUŽITÍM FREKVENČNÍCH A ČASOVĚ FREKVENČNÍCH METOD**

Jaroslav SMUTNÝ

Obsahem příspěvku je srovnání konstrukce klasického kolejového svršku s nově navrženým protihlukovým a protivibračním opatřením.

Dále příspěvek prezentuje analýzu hluku a vibrací klasických a upravených tramvajových kol (konstrukce s pryžovým segmentem od firmy ŽDB Bohumín).

## Summary

### **ANALYSIS OF SOME NOISE AND VIBRATION REDUCTION ACQUISITION ON URBAN TRAMVAY TRANSPORT BY USING FREQUENCY AND TIME FREQUENCY TECHNIQUES**

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A comparison has been made common track and track equipped with specially designed rubber elements in terms of reduction of noise and vibration due to tram operation.

Next, the article presents the analysis of noise and vibration conditions of the tramcar with classical and changed wheel design (construction with rubber dampers constructed by the company ŽDB Bohumín).

## Zusammenfassung

### **DIE ANALYSE DER LÄRM UND VIBRATIONS VERSCHAFFUNG AN STRAßENBAHNEWAGEN MIT DER APLIKATION MODERNEN FREQUENZ UND ZEIT-FREQUENZ TECHNIKEN**

Jaroslav SMUTNÝ

In der Artikel wird verglichen die klassische Oberbaukonstruktion mit dem mit speziellen Gummielementen versehen Oberbau aus Sichtpunkt der Absenkung von durch Bahnverkehr verursachten Lärm und Vibrationen.

Weiter, der Artikel befasst sich mit der Analyse von Lärm und Vibrationsverhältnissen beim Befahren einer Wendeschleife von dem Strassenbahnwagen mit klassischer und veränderter Radkonstruktion.

