9. Function of exposure time to the vibration of defined frequency bands in research on the influence of the technical condition of suspension elements and of the vehicle operating parameters on the vibration

The time-frequency representations of the structure of the vibration presented in previous chapter enable selective evaluation of exposure to vibration in means of transport. For the purpose of analysis of the influence of the technical condition of suspension elements and of the vehicle operating parameters on the vibration propagation it is useful to identify the components of the signal which are best representation of those influences. Thus the symptoms of the technical conditions or value of the operating parameters can be determined.

The vibration occurring during research are results of forces acting on wheel by the exciter machine. The signals have non-stationary properties. Thus the evaluation of human vibration exposure based on global estimators is difficult. Distribution of the vibration in defined frequency bands enables observing of vibration exposition in time function.

9.1. Distribution of the vibration of defined frequency bands

Basing on the analysis of the results presented in Chapters 7 and 8 the main frequency bands were chosen for further observation. The obtained representation of the vibration as structure of STFT transformation allow to determine time function of separate frequency bands which represents the isolated vibration dynamics phenomena, expressed as:

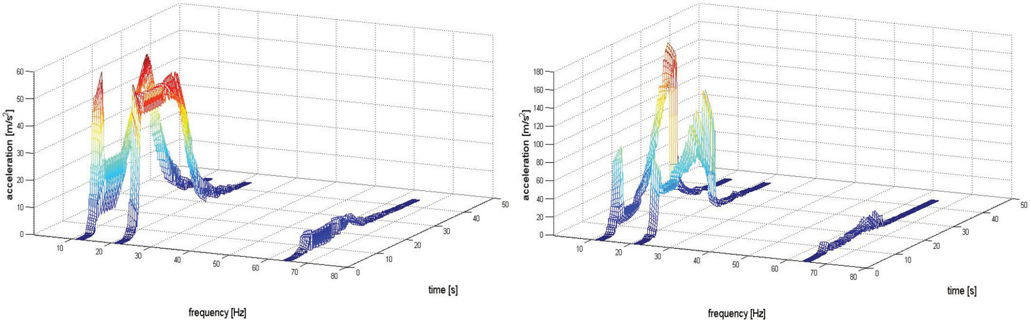
$$S_f = \sum_{f=a}^{b} \sum_{i=0}^{\infty} S(\omega_f, t_i), \tag{9.1}$$

where: f – frequency band from a to b, t – time, $S(\omega_f, t_i)$ – Short-Time Fourier Transformation of the signal.

This function allows separation of the chosen dynamics structure of the vibration and analysis of energy changes by the time realization in isolated frequency bands.

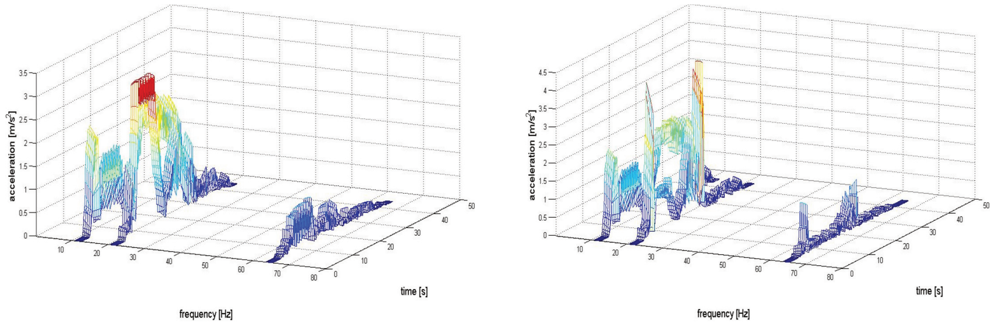
This method of identification of vibration dynamics allows to observe time of increase of vibration activity of the vehicle and influence of the damping properties on time function of the chosen frequency bands of the signal. Results analysis of vibration structure, presented in previous chapter, occurred during research on different damping properties of shock absorbers it was assumed that the most sensitivity frequency components are ca. 12 Hz, 21.5 Hz and 64.5 Hz. There were set as centers of the analysed frequency bands range ca. 2 Hz each. Figs. 9.1-9.6 present time distribution of the vibration in those frequencies.

The presented method has been tested too on results of research on influence of tire pressure on vibration propagation in vehicle construction. Results analysis of vibration structure, presented in previous chapter, it was assumed that the most sensitivity frequency components are ca. 5 Hz, 15 Hz and 21.5 Hz. Figs. 9.7-9.12 present time distribution of the vibration in those frequencies.



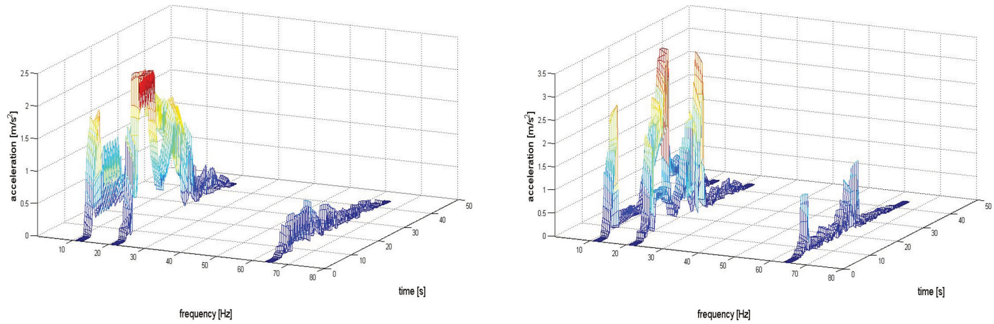
a) Shock absorber with 100 % of liquid volume b) Shock absorber with 50 % of liquid volume

Fig. 9.1. Time-frequency distribution of the vibration of suspension arm



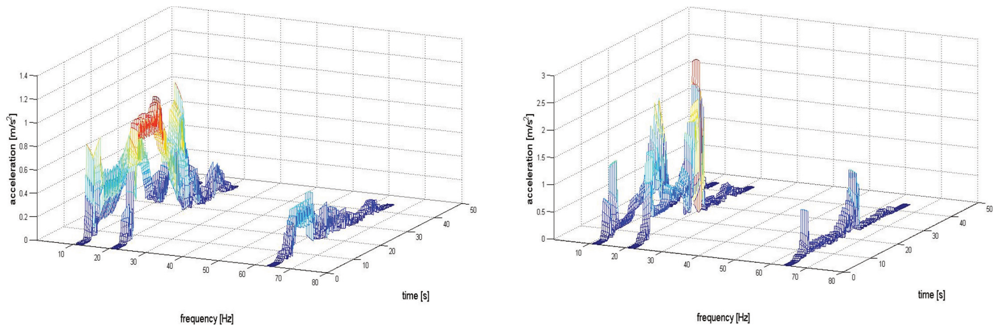
a) Shock absorber with 100 % of liquid volume b) Shock absorber with 50 % of liquid volume

Fig. 9.2. Time distribution of the vibration in chosen frequency bands of upper mounting of shock absorber



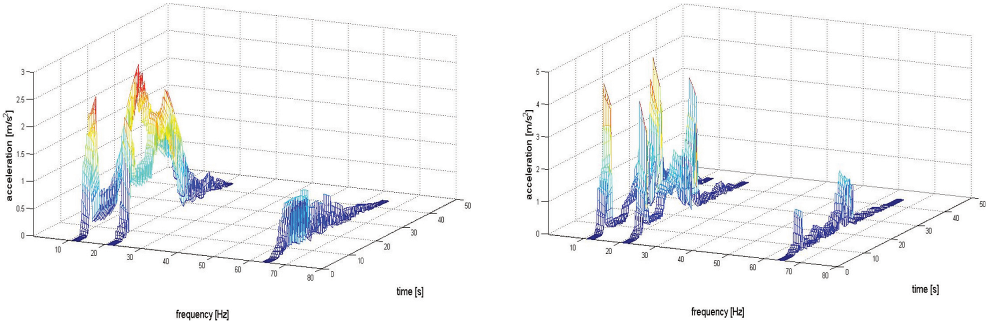
a) Shock absorber with 100 % of liquid volume b) Shock absorber with 50 % of liquid volume

Fig. 9.3. Time distribution of the vibration in chosen frequency bands of floor under driver's feet



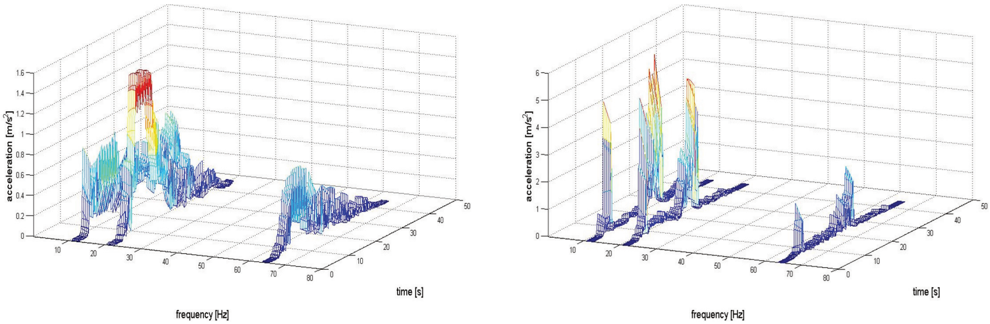
a) Shock absorber with 100 % of liquid volume b) Shock absorber with 50 % of liquid volume

Fig. 9.4. Time distribution of the vibration in chosen frequency bands of floor under front passenger's feet



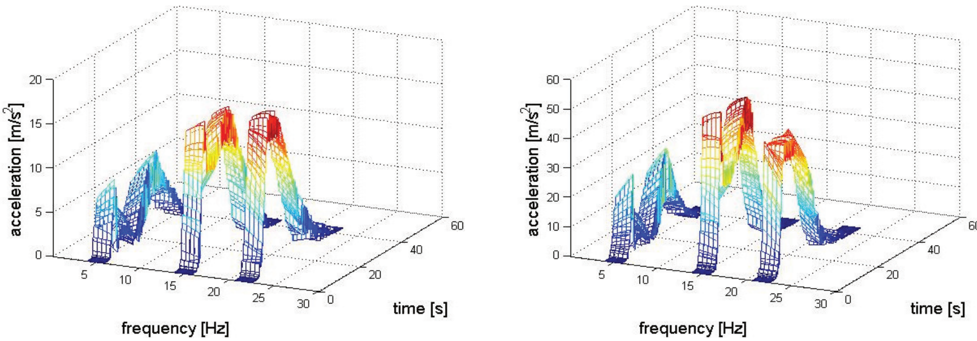
a) Shock absorber with 100 % of liquid volume   b) Shock absorber with 50 % of liquid volume

Fig. 9.5. Time distribution of the vibration in chosen frequency bands of floor under rear left passenger's feet

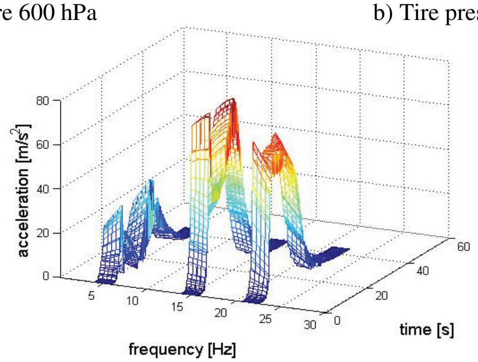


a) Shock absorber with 100 % of liquid volume   b) Shock absorber with 50 % of liquid volume

Fig. 9.6. Time distribution of the vibration in chosen frequency bands of floor under rear right passenger's feet

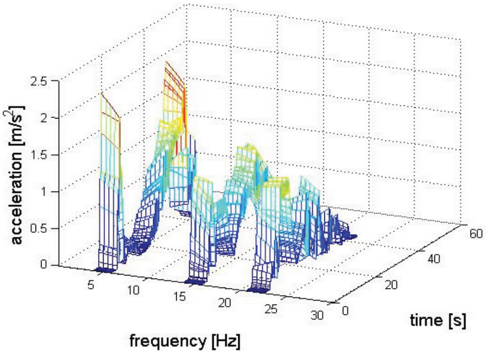


a) Tire pressure 600 hPa   b) Tire pressure 1800 hPa

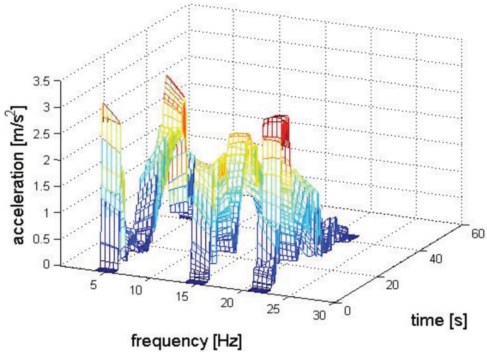


c) Tire pressure 2600 hPa

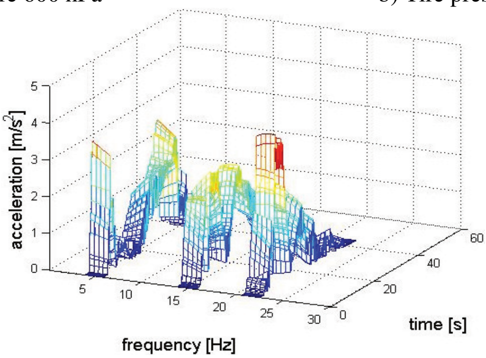
Fig. 9.7. Time distribution of the vibration in chosen frequency bands of suspension arm



a) Tire pressure 600 hPa

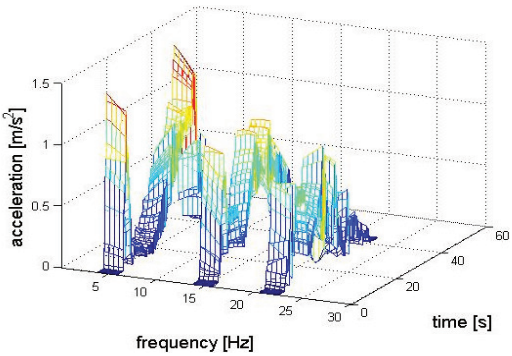


b) Tire pressure 1800 hPa

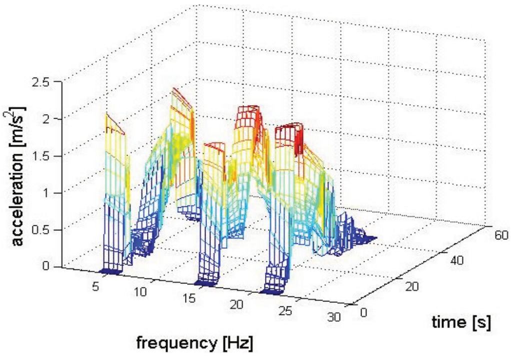


c) Tire pressure 2600 hPa

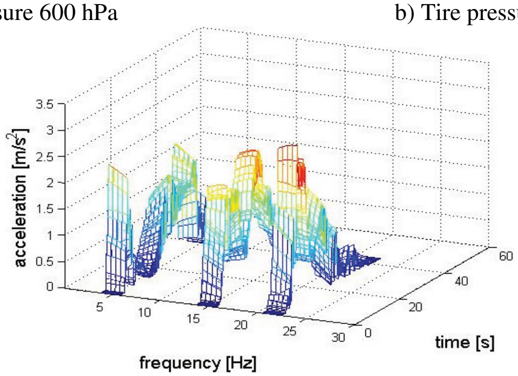
Fig. 9.8. Time distribution of the vibration in chosen frequency bands of upper mounting of shock absorber



a) Tire pressure 600 hPa



b) Tire pressure 1800 hPa



c) Tire pressure 2600 hPa

Fig. 9.9. Time distribution of the vibration in chosen frequency bands of floor under driver's feet

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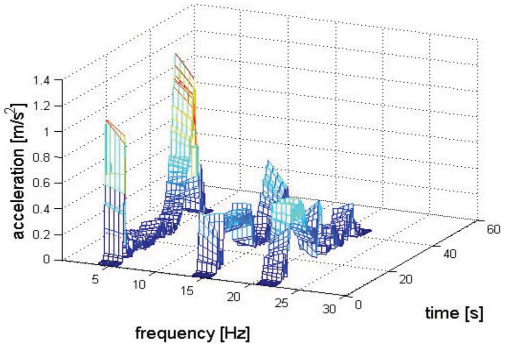
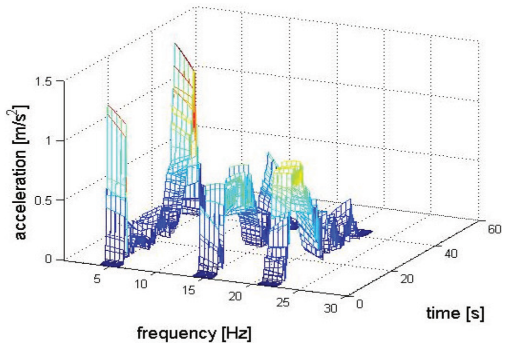
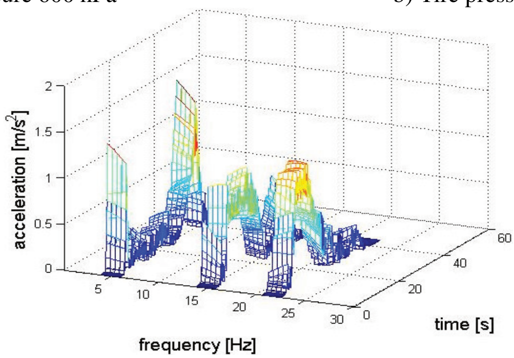


a) Tire pressure 600 hPa

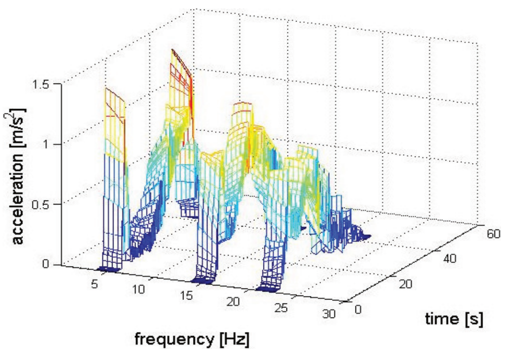


b) Tire pressure 1800 hPa

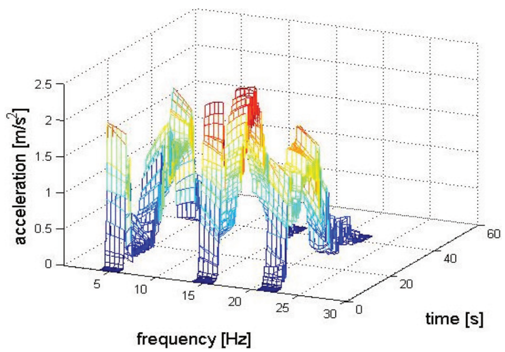


c) Tire pressure 2600 hPa

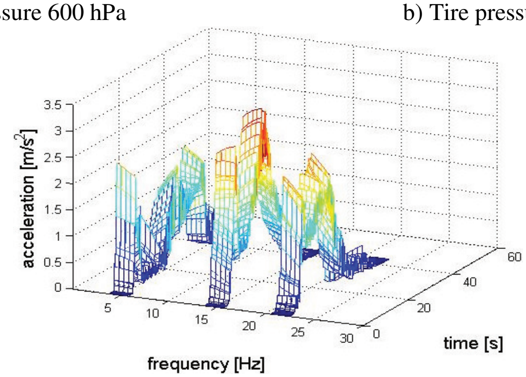
Fig. 9.10. Time distribution of the vibration in chosen frequency bands of floor under front passenger's feet



a) Tire pressure 600 hPa

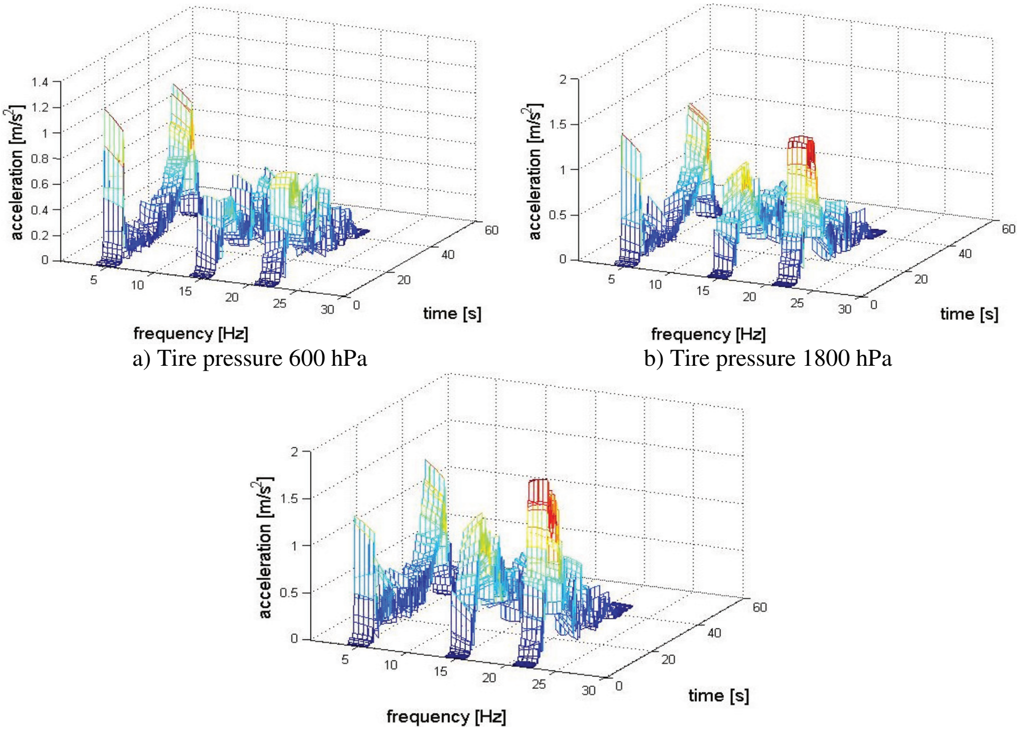


b) Tire pressure 1800 hPa



c) Tire pressure 2600 hPa

Fig. 9.11. Time distribution of the vibration in chosen frequency bands of floor under rear left passenger's feet



a) Tire pressure 600 hPa b) Tire pressure 1800 hPa

c) Tire pressure 2600 hPa

Fig. 9.12. Time distribution of the vibration in chosen frequency bands of floor under rear right passenger's feet

9.2. Function of exposure time to the vibration of defined frequency bands

Considering the variability of the time and frequency distribution of the vibration even in selected analyzed bands, the time function was developed as vibration exposure estimator. It is calculated of average value of frequency bands vibration in time domain, expressed as:

$$S_{avr} = \sum_{i=0}^{\infty}\left(\frac{1}{\frac{b-a}{d}}\sum_{f=a}^{b} S(\omega_f, t_i)\right), \tag{9.2}$$

where: a – lover edge of the passband, b – upper edge of the passband, d – STFT frequency resolution (integer rounded value), $(b-a)/d$ – returns number of samples in frequency bands.

Fig. 9.13 presents process of the determination of the average value of frequency bands vibration 11-13 Hz, in time domain.

Fig. 9.14 shows the comparison of the time function of average vibration in those frequency band for the car with shock absorber with 100 % and 50 % of liquid volume.

Figs. 9.15-9.20 present the comparison of time function of average vibration in chosen frequency bands for the vehicle with build in shock absorber with 100 % and 50 % of liquid volume. The chapter presents result obtained for the following frequencies bands: 11-13 Hz (Figs. 9.13 and 9.14), 20.5-22.5 Hz and 63.5-65.5 Hz.

The comparison of time function of average vibration in chosen frequency bands for the vehicle with tire pressure 600 hPa, 1800 hPa (nominal) and 2600 hPa have been depicted in Figs. 9.21-9.26. The chapter presents result obtained for the frequencies bands: 4-6 Hz, 14-16 Hz and 20.5-22.5 Hz.

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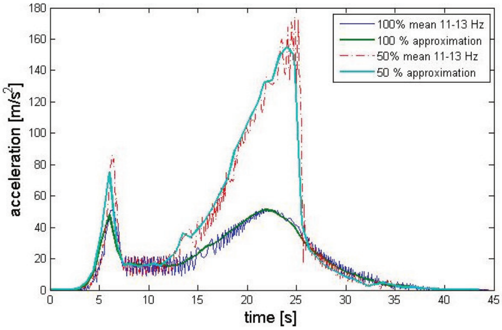
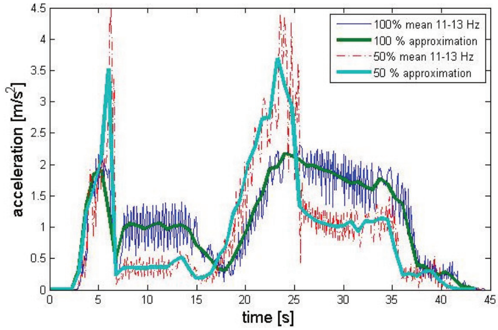
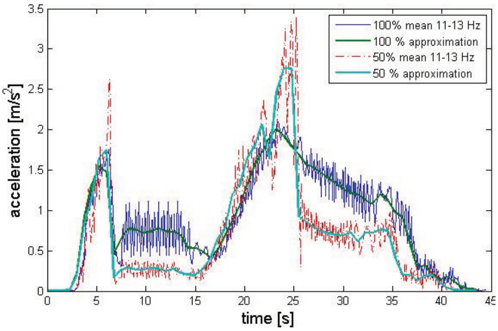


a) Suspension arm

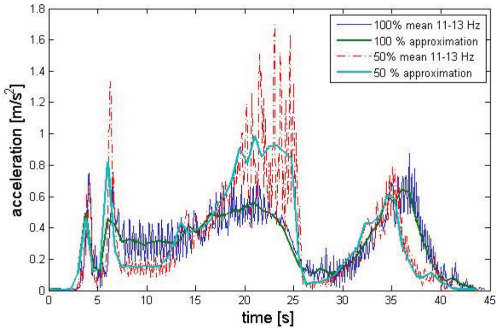


b) Upper mounting of shock absorber

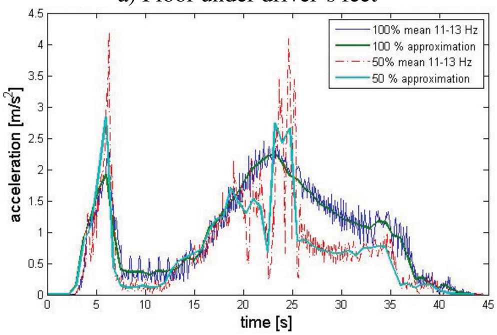
Fig. 9.13. The process of the determination of the average value of frequency bands vibration (11-13 Hz) in time domain



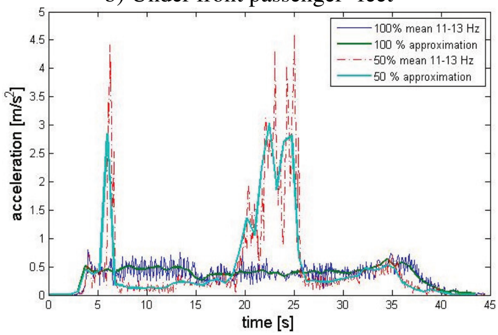
a) Floor under driver's feet



b) Under front passenger' feet

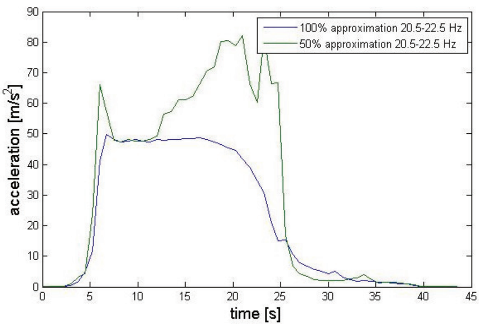


c) Under rear left passenger' feet

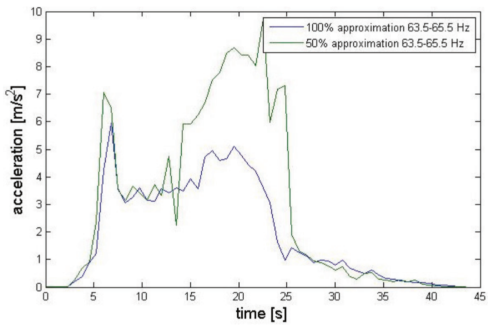


d) Under rear right passenger' feet

Fig. 9.14. The process of the determination of the average value of frequency bands vibration (11-13 Hz) in time domain

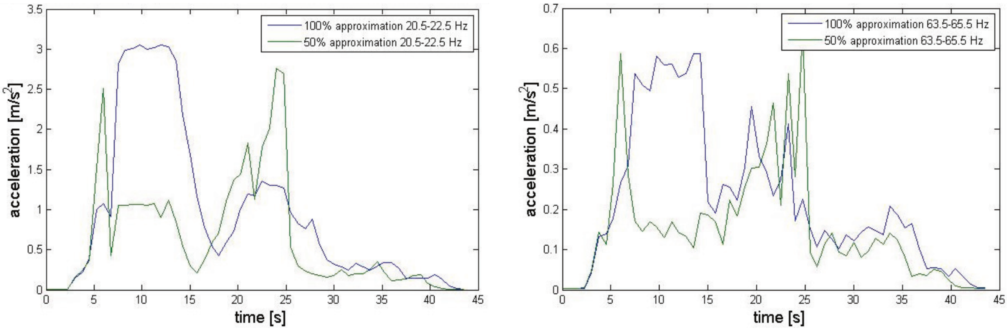


a) 20.5-22.5 Hz



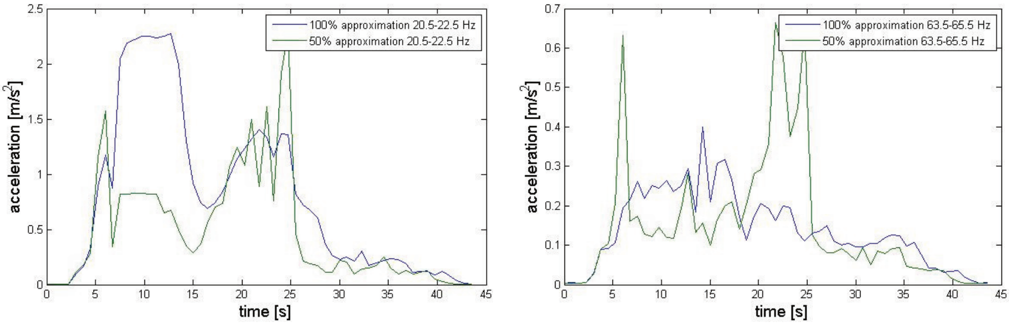
b) 63.5-65.5 Hz

Fig. 9.15. Time function of average vibration in frequency bands: suspension arm of shock absorber



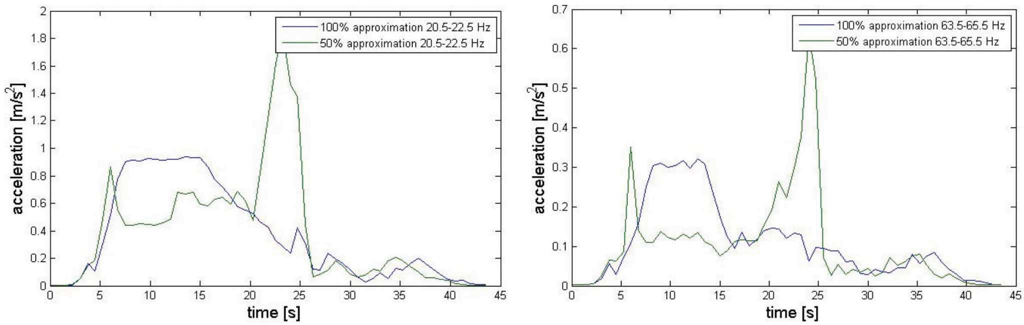
a) 20.5-22.5 Hz b) 63.5-65.5 Hz

Fig. 9.16. Time function of average vibration in frequency bands: upper mounting of shock absorber



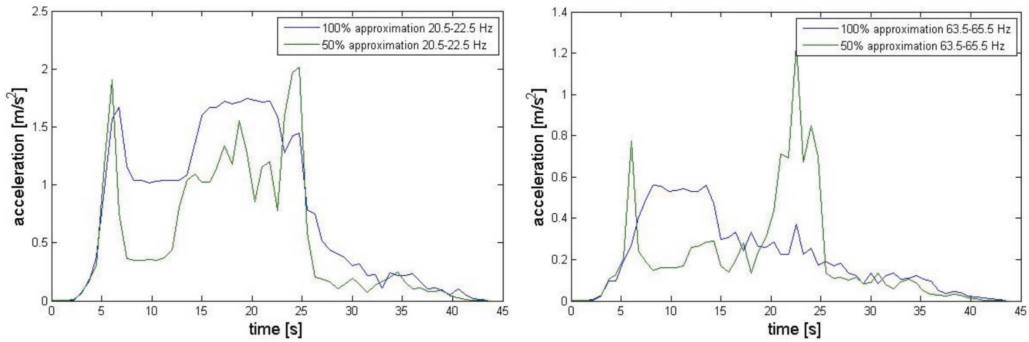
a) 20.5-22.5 Hz b) 63.5-65.5 Hz

Fig. 9.17. Time function of average vibration in frequency bands: floor under driver's feet



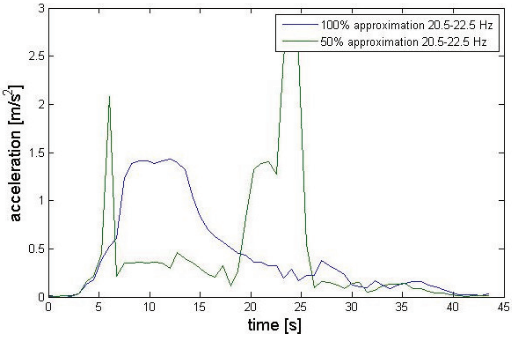
a) 20.5-22.5 Hz b) 63.5-65.5 Hz

Fig. 9.18. Time function of average vibration in frequency bands: floor under front passenger's feet

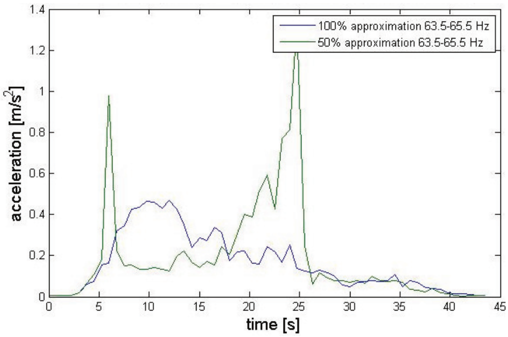


a) 20.5-22.5 Hz b) 63.5-65.5 Hz

Fig. 9.19. Time function of average vibration in frequency bands: floor under rear left passenger's feet

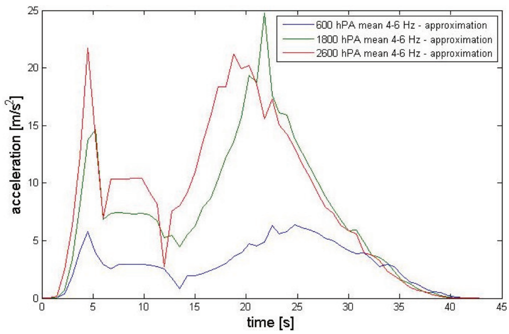


a) 20.5-22.5 Hz

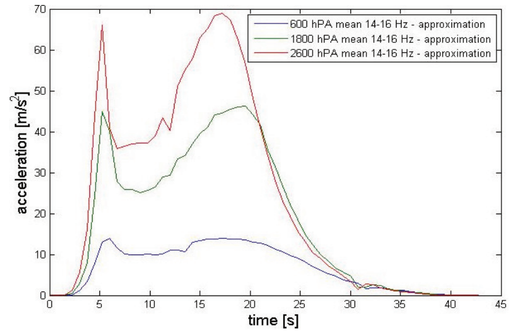


b) 63.5-65.5 Hz

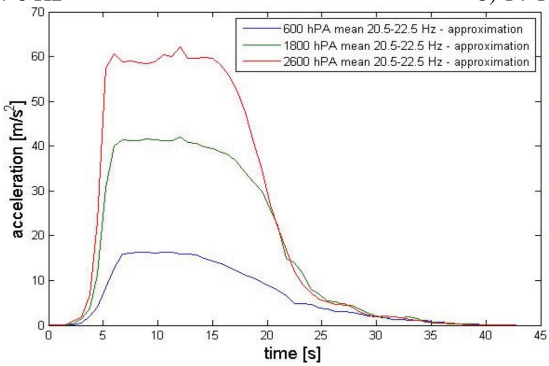
Fig. 9.20. Time function of average vibration in frequency bands: floor under rear right passenger's feet



a) 4-6 Hz



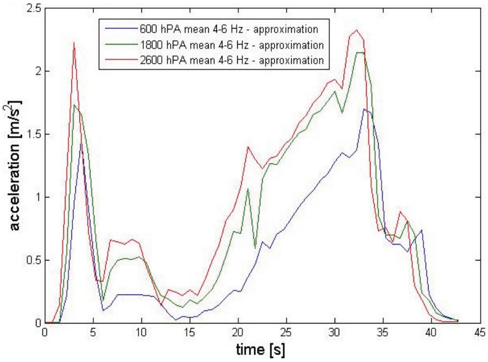
b) 14-16 Hz



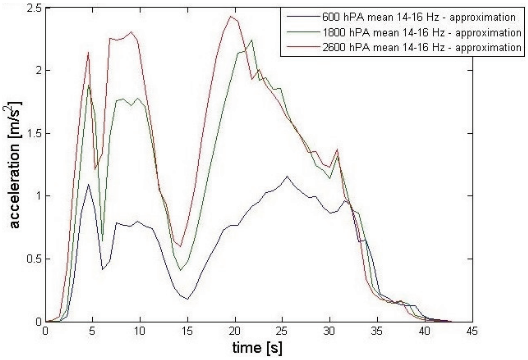
c) 20.5-22.5 Hz

Fig. 9.21. Time function of average vibration of suspension arm in frequency bands

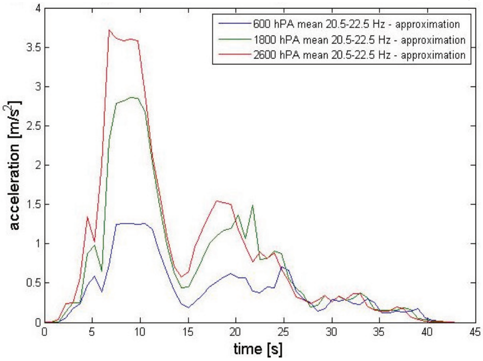
Previous chapter presents the application of STFT 3-D time-frequency distributions for proper observation of the vibration structure. The obtained representation of the vibration allow to determine time function of separate frequency bands represents the isolated vibration dynamics phenomena. The changes of the vibration energy in chosen frequency bands can be observed by the time function of average vibration in chosen frequency bands. The results of comparison of the vibration of the vehicle with build in shock absorber with 100 % and 50 % of liquid volume show the influence of damping properties on chosen frequency bands. The analysis of the results shows increase of the vibration energy for the vehicle with shock absorber with 50 % of liquid volume but for determined time realization. For the rest of the time of excitation the vibration are even lower, especially during constant excitation (ca. between 9-14 second). The maximums values of the functions are in ca. 5th and 25th seconds of the excitation. It is the effect of time of passing thru unsprung masses resonance, ca. 12 Hz.



a) 4-6 Hz

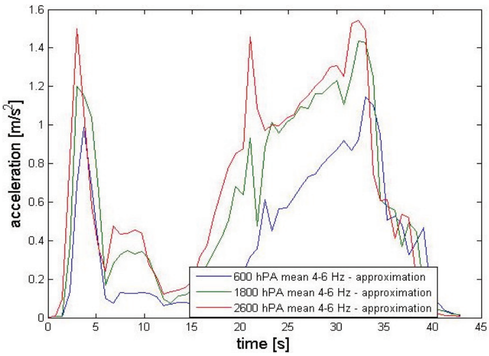


b) 14-16 Hz

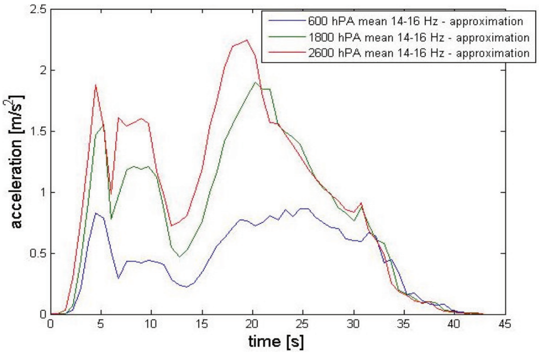


c) 20.5-22.5 Hz

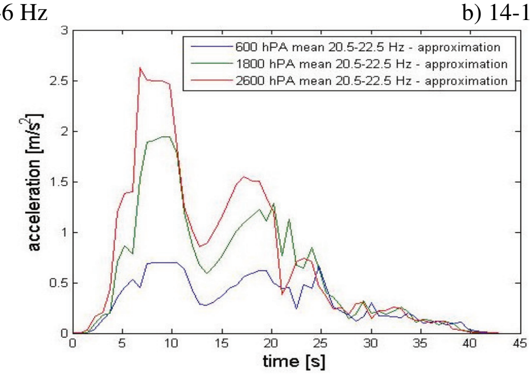
Fig. 9.22. Time function of average vibration of upper mounting of shock absorber in frequency bands



a) 4-6 Hz

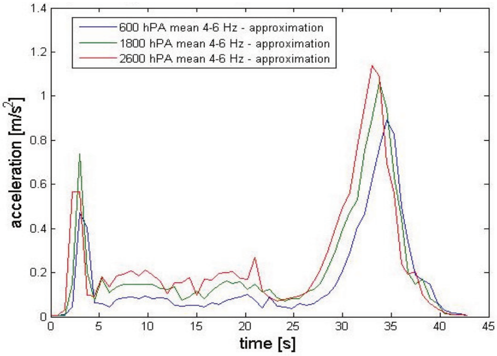


b) 14-16 Hz

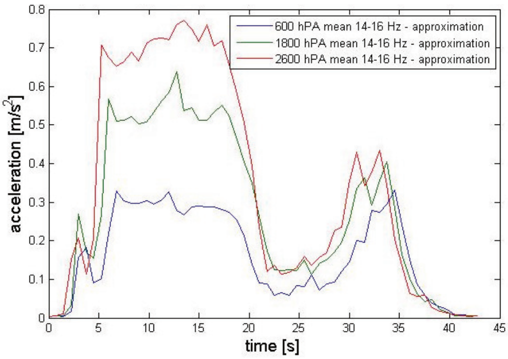


c) 20.5-22.5 Hz

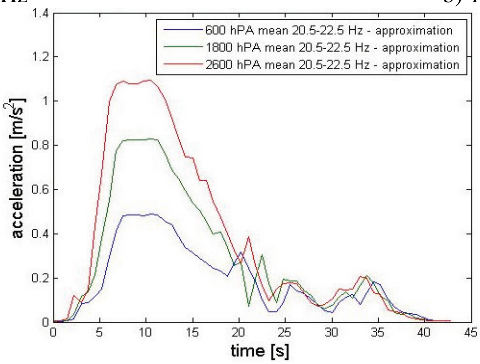
Fig. 9.23. Time function of average vibration of floor under driver's feet in frequency bands



a) 4-6 Hz

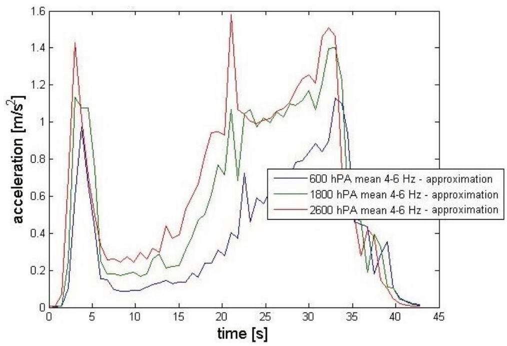


b) 14-16 Hz

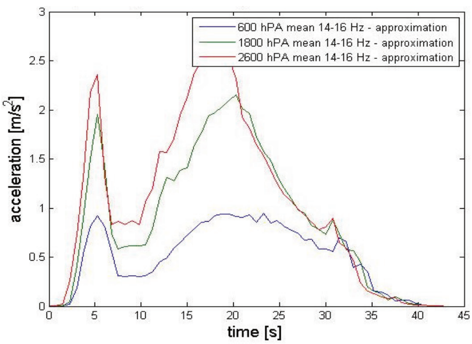


c) 20.5-22.5 Hz

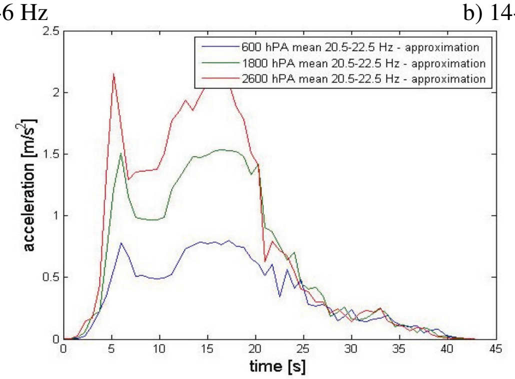
Fig. 9.24. Time function of average vibration of floor under front passenger's feet in frequency bands



a) 4-6 Hz

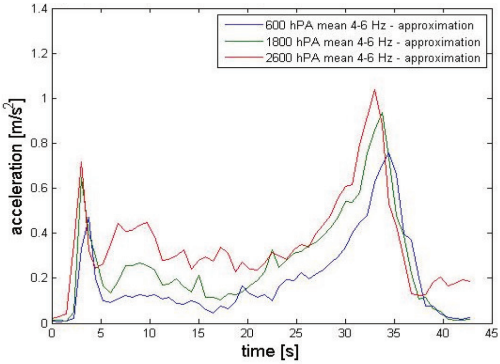


b) 14-16 Hz

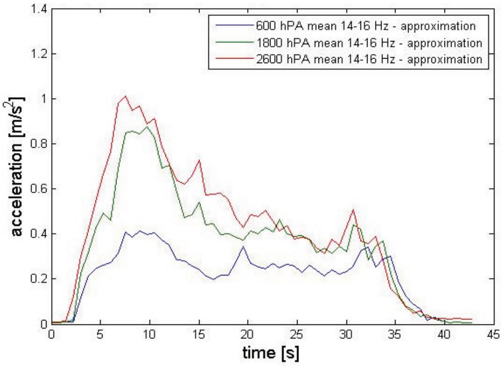


c) 20.5-22.5 Hz

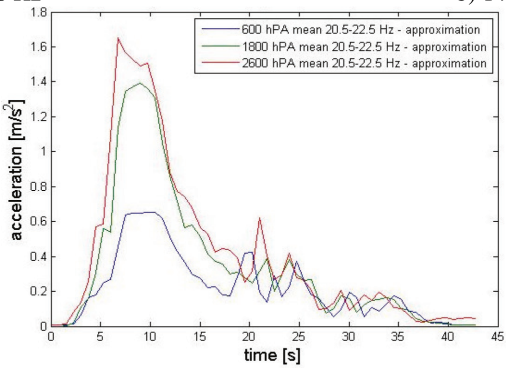
Fig. 9.25. Time function of average vibration of floor under rear left passenger's feet in frequency bands



a) 4-6 Hz



b) 14-16 Hz



c) 20.5-22.5 Hz

Fig. 9.26. Time function of average vibration of floor under rear right passenger's feet in frequency bands

The results of time function of average vibration in chosen frequency bands for the vehicle with tire pressure 600 hPa, 1800 hPa (nominal) and 2600 hPa represents very sensitivity symptom estimator. Almost in every investigated case the functions were totally separable in whole time domain. The trend of increase of vibration due to increase of pressure in tire was noticeable for all results. The local maximum of the function can be localized ca. 5, 20 and 35 seconds.

Very important conclusion is that function proposed of exposure time to the vibration of defined frequency bands is sensitivity for vibration of the floor panel in location of driver and passengers feet. This is the place of vibration transfer from vehicle via feet to the humans in mean of transport. Thus formulated and developed function may be useful for exposure to vibration evaluation or monitoring.