10. Resonance spectrum in research on the influence of the technical condition of suspension elements and of the vehicle operating parameters on the vibration

The functions of exposure time to the vibration of defined frequency bands (S_f, S_{avr}) facilitate the identification and location of the time of increase of vibration activity of the mechanical system. The increase of vibration energy dissipation can be result of resonance occurring. For the mechanical system with the masses of the motor vehicle almost the total vibration energy can be related to the 2 types of resonances, of sprung and unsprung masses. For the purpose of evaluation of vibration in terms of human perception and exposure it is important to observe energy of the vibration in frequency bands correlated to the natural vibration of human organs. Thus the expanded methodology for identification of dominant frequency components forced during the resonance is developed. As result of the methodology the function estimator as resonance spectrum is determined.

10.1. Spectrum of the vibration occurring during resonance

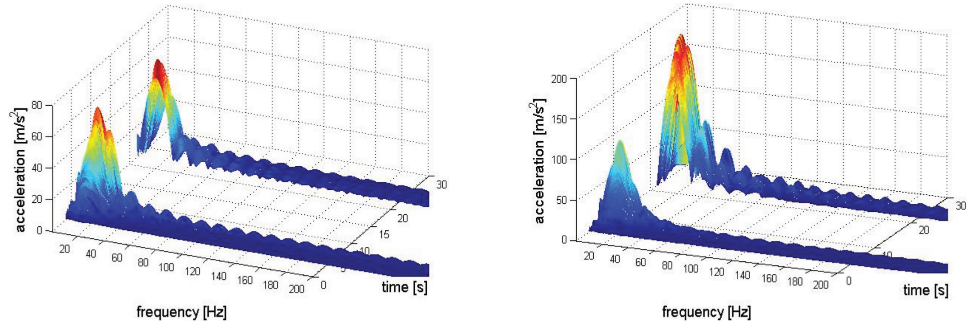
Basing on the analysis of the time course of vibration in chosen frequencies bands, presented in previous chapter, the time of increased energy of vibration propagation can be clearly indicated. It can be result of passing by resonance frequency by this time. For observation of frequencies carrying most of the vibration energy the function of frequency distribution for determined time period was calculated and is expressed as:

$$S_t = \sum_{t=a}^{b} \sum_{f=0}^{\infty} S(\omega_f, t_i), \tag{10.1}$$

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

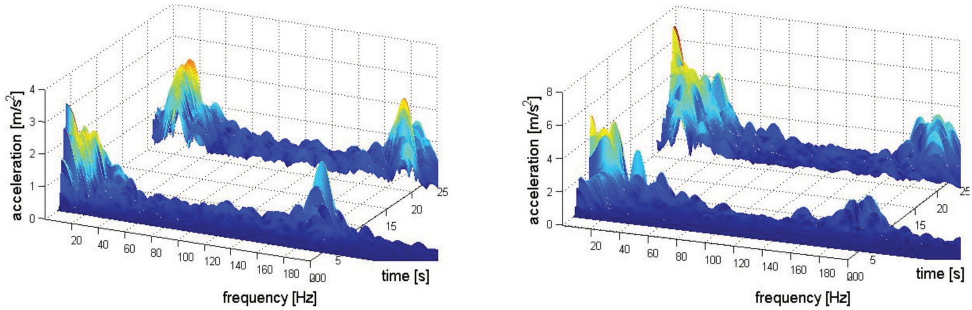
The obtained results of research on influence of damping properties of shock absorbers on vehicle vibration, for all investigated cases, show that vibration occurs in ca. 5 and 25 seconds are higher. Figs. 10.1-10.6 present frequency distribution of the vibration for resonance passing.

The S_t structure was calculated from results of research on influence of tire pressure on vibration propagation in vehicle construction. Results analysis of vibration structure, presented in previous chapter, confirms the increase of vibration occurring at ca. 4 s, 20 s and 34 s. Figures below present frequency distribution of the vibration for those time passing.



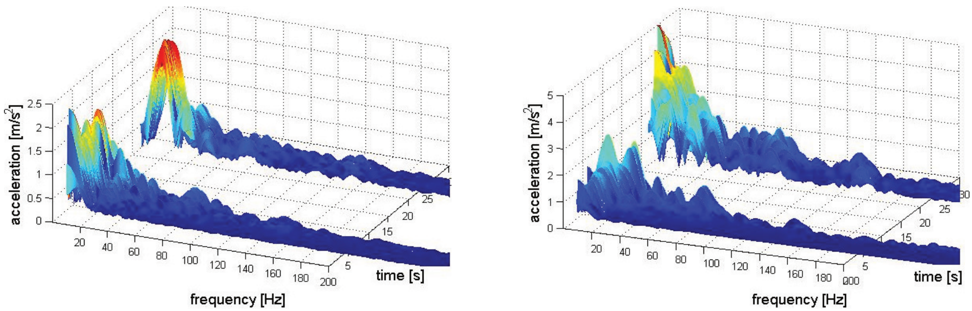
a) Shock absorber with 100 % of liquid volume b) Shock absorber with 50 % of liquid volume

Fig. 10.1. Frequency distribution of the vibration for resonance passing of suspension arm



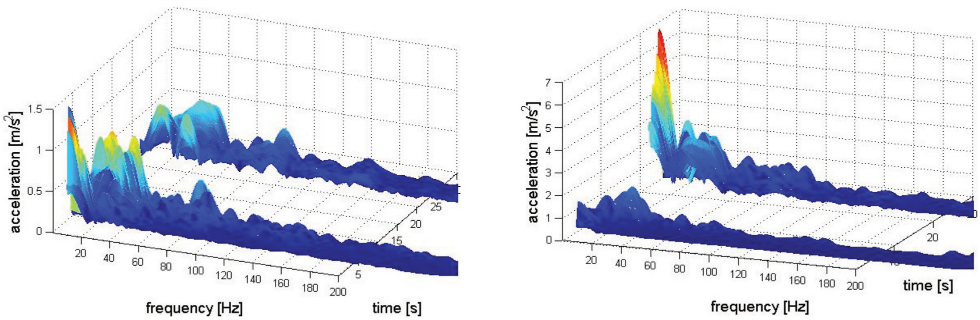
a) Shock absorber with 100 % of liquid volume b) Shock absorber with 50 % of liquid volume

Fig. 10.2. Frequency distribution of the vibration for resonance passing of upper mounting of shock absorber



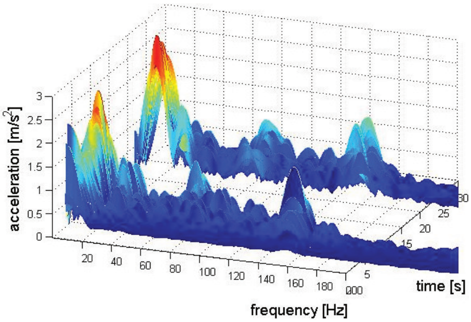
a) Shock absorber with 100 % of liquid volume b) Shock absorber with 50 % of liquid volume

Fig. 10.3. Frequency distribution of the vibration for resonance passing of floor under driver's feet

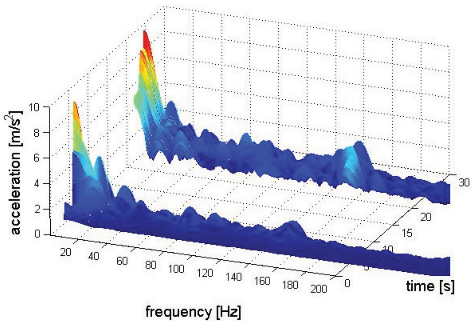


a) Shock absorber with 100 % of liquid volume b) Shock absorber with 50 % of liquid volume

Fig. 10.4. Frequency distribution of the vibration for resonance passing of floor under front passenger's feet

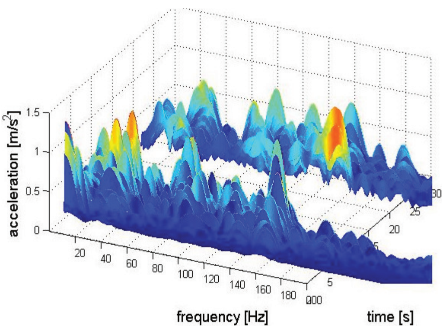


a) Shock absorber with 100 % of liquid volume

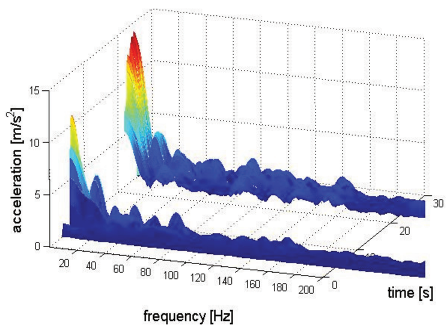


b) Shock absorber with 50 % of liquid volume

Fig. 10.5. Frequency distribution of the vibration for resonance passing of floor under rear left passenger's feet

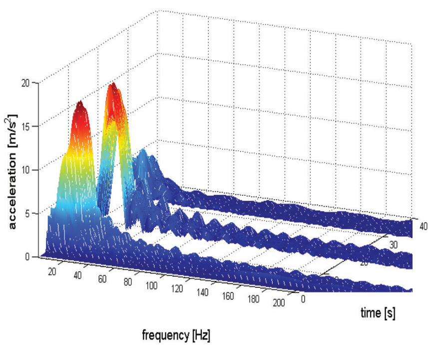


a) Shock absorber with 100 % of liquid volume

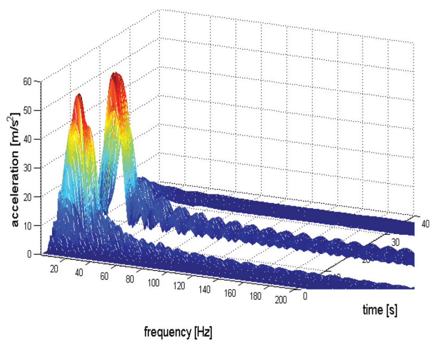


b) Shock absorber with 50 % of liquid volume

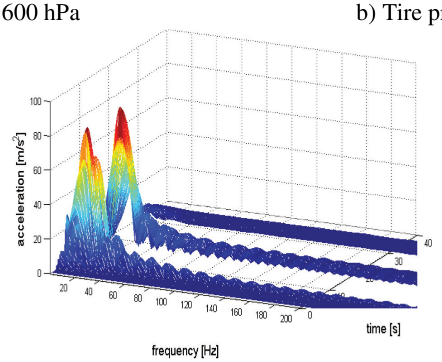
Fig. 10.6. Frequency distribution of the vibration for resonance passing of floor under rear right passenger's feet



a) Tire pressure 600 hPa

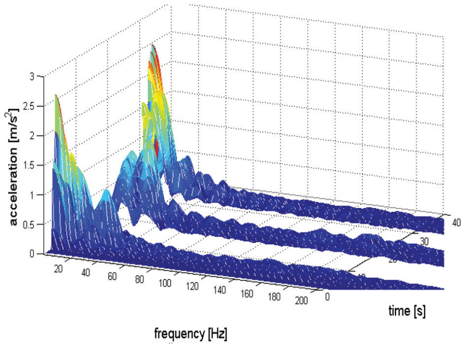


b) Tire pressure 1800 hPa

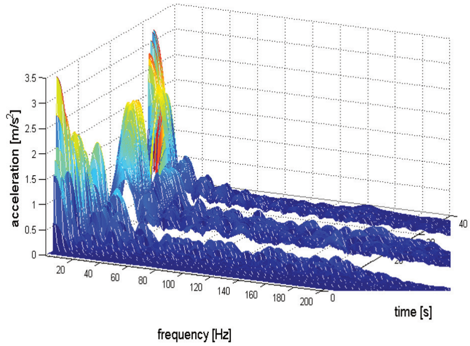


c) Tire pressure 2600 hPa

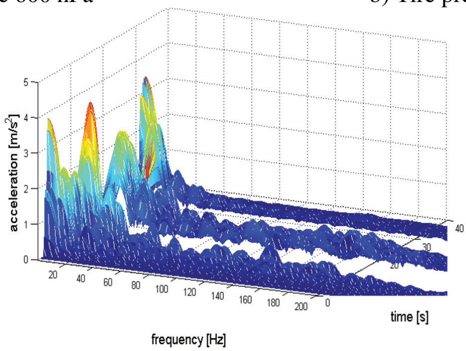
Fig. 10.7. Frequency distribution of the vibration for resonance passing of suspension arm



a) Tire pressure 600 hPa

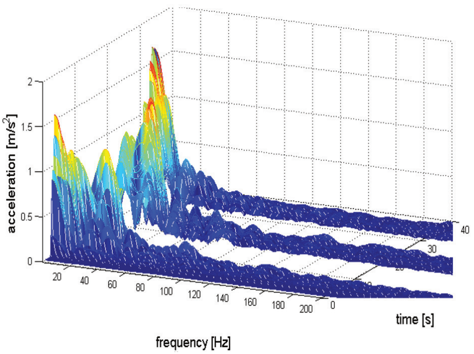


b) Tire pressure 1800 hPa

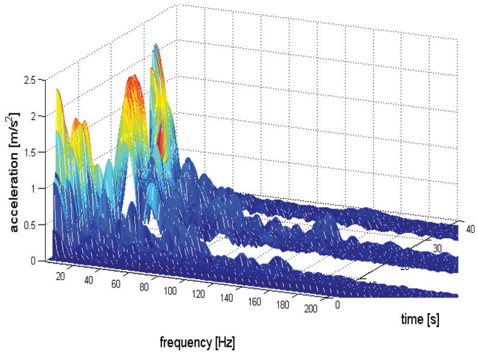


c) Tire pressure 2600 hPa

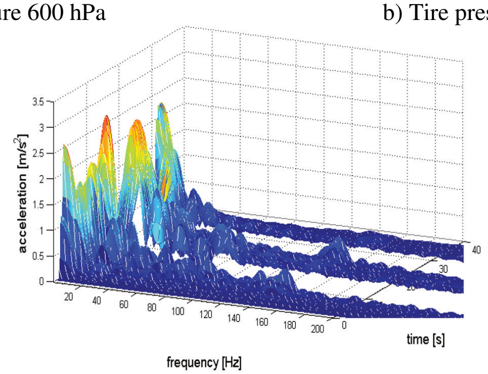
Fig. 10.8. Frequency distribution of the vibration for resonance passing of upper mounting of shock absorber



a) Tire pressure 600 hPa

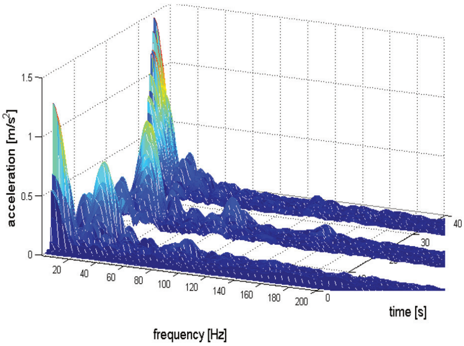


b) Tire pressure 1800 hPa

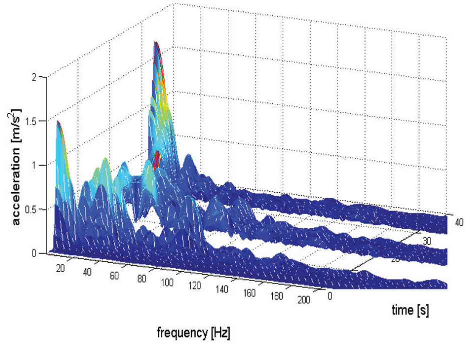


c) Tire pressure 2600 hPa

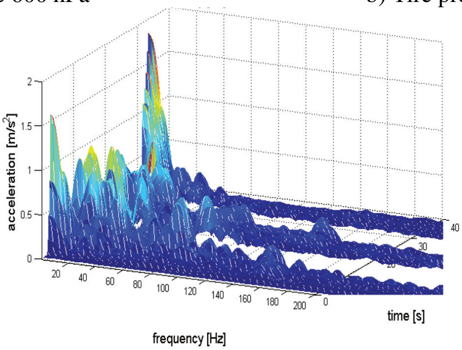
Fig. 10.9. Frequency distribution of the vibration for resonance passing of floor under driver's feet



a) Tire pressure 600 hPa

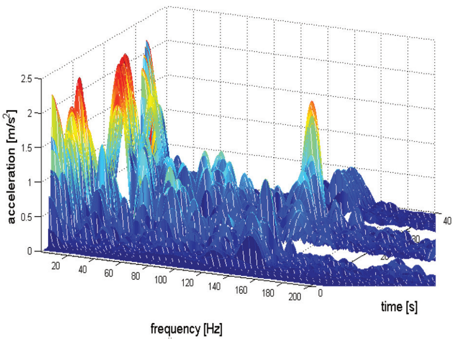


b) Tire pressure 1800 hPa

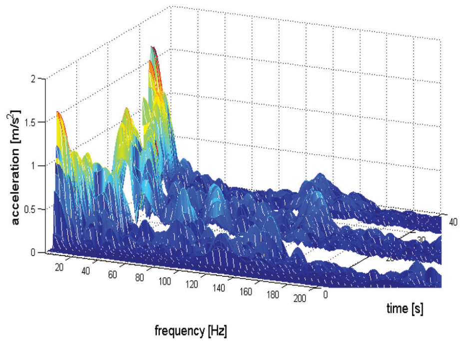


c) Tire pressure 2600 hPa

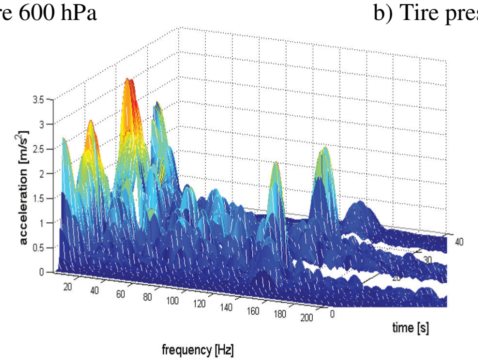
Fig. 10.10. Frequency distribution of the vibration for resonance passing of floor under front passenger's feet



a) Tire pressure 600 hPa

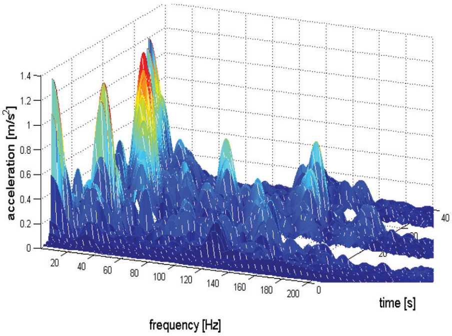


b) Tire pressure 1800 hPa

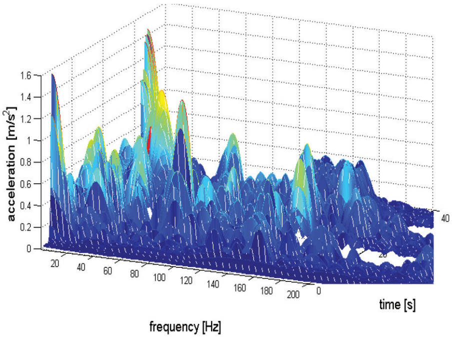


c) Tire pressure 2600 hPa

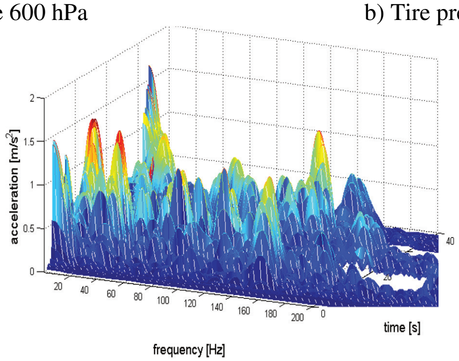
Fig. 10.11. Frequency distribution of the vibration for resonance passing of floor under rear left passenger's feet



a) Tire pressure 600 hPa



b) Tire pressure 1800 hPa



c) Tire pressure 2600 hPa

Fig. 10.12. Frequency distribution of the vibration for resonance passing of floor under rear right passenger's feet

10.2. Resonance spectrum – vibration function

The S_t structures of vibration represent dominant dynamics components of vibration excited during most vibro-activity time of exposure. The matrix form of S_t can make some difficulties in fast interpretation, especially for the purpose of the comparison. Thus the frequency function have been developed as vibration dynamics exposure estimator. It is calculated of average value of time period vibration in frequency domain, expressed as:

$$S_{Tavr} = \sum_{f=0}^{\infty}\left(\frac{1}{(b-a)/d}\sum_{t=a}^{b} S(\omega_f, t_i)\right), \quad (10.2)$$

where: a – start of the time period, b – end of the time period, d – STFT time resolution (integer rounded value), $(b-a)/d$ – returns number of samples in time period.

The process of the determination of the average value of time period vibration in frequency domain, as result of S_{Tavr} function, is similar to the process of determination of S_{avr} function presented in Figs. 9.13 and 9.14. The difference is frequency domain instead time domain.

The comparison of frequency function of average vibration in chosen time period for the vehicle with build in shock absorber with 100 % and 50 % of liquid volume is presented in Figs. 10.13-10.18.

The comparison of frequency function of average vibration in chosen time period for the vehicle with tire pressure 600 hPa, 1800 hPa (nominal) and 2600 hPa have been depicted in Figs. 10.19-10.24. The chapter presents result obtained for the time periods: 1-7 s, 17-23 s and 31-37 s.

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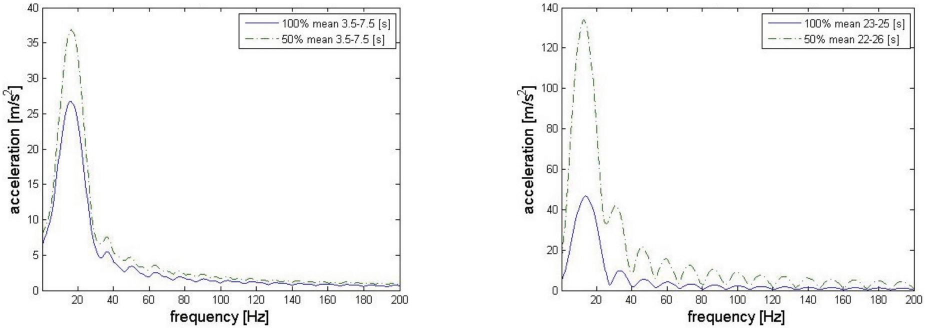
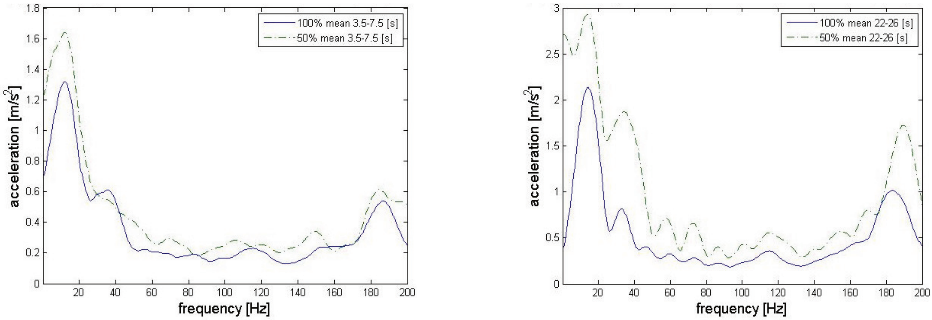


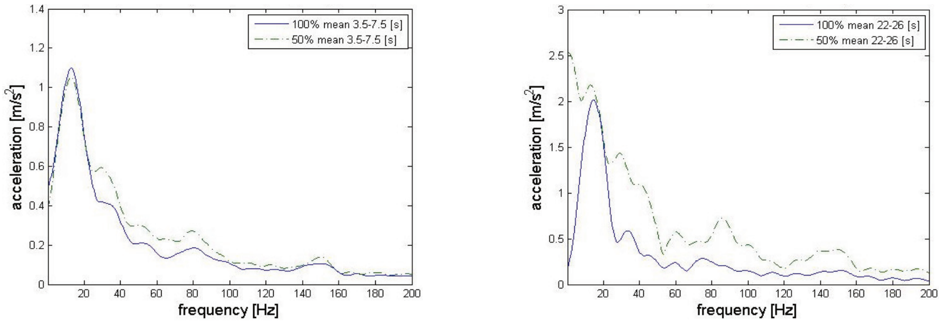
a) 3.5-7.5 s b) 22-26 s

Fig. 10.13. Frequency function of average vibration in time periods: suspension arm



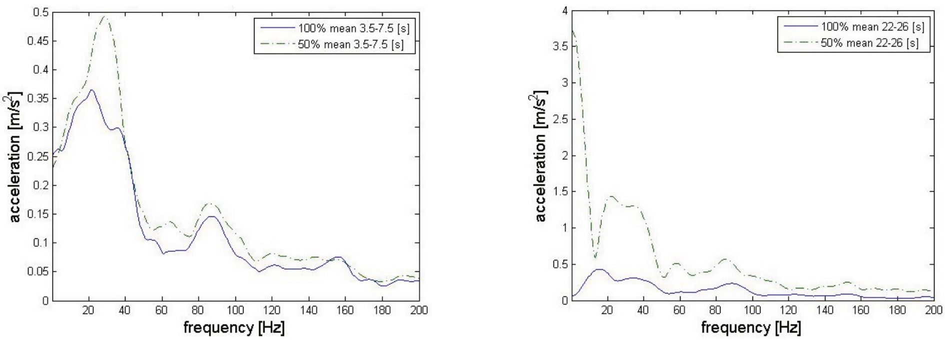
a) 3.5-7.5 s b) 22-26 s

Fig. 10.14. Frequency function of average vibration in time periods: upper mounting of shock absorber



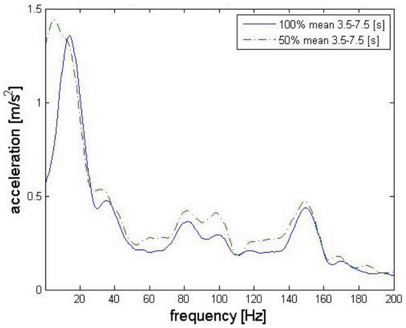
a) 3.5-7.5 s b) 22-26 s

Fig. 10.15. Frequency function of average vibration in time periods: floor under driver's feet

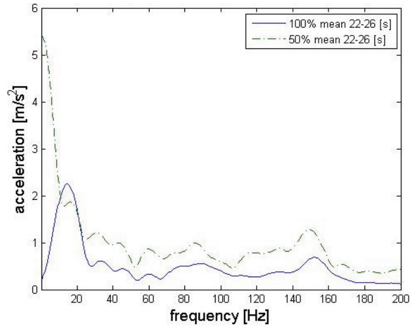


a) 3.5-7.5 s b) 22-26 s

Fig. 10.16. Frequency function of average vibration in time periods: floor under front passenger's feet

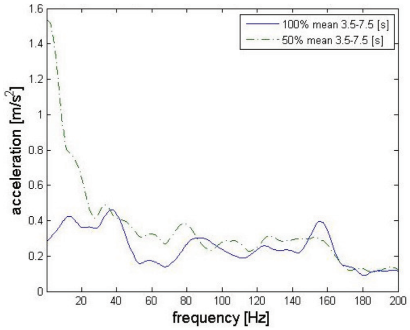


a) 3.5-7.5 s

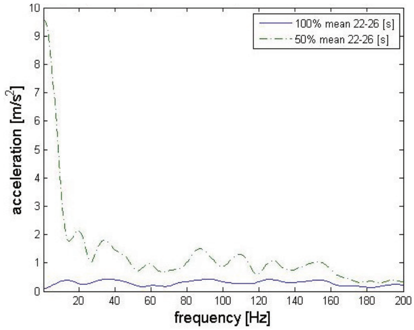


b) 22-26 s

Fig. 10.17. Frequency function of average vibration in time periods: floor under rear left passenger’s feet

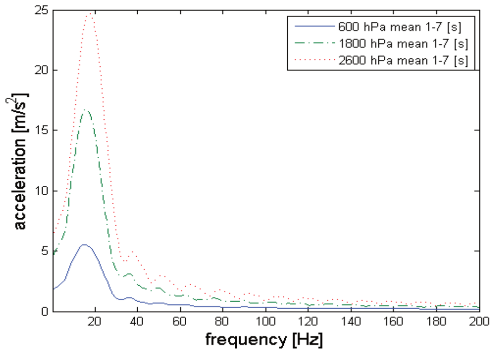


a) 3.5-7.5 s

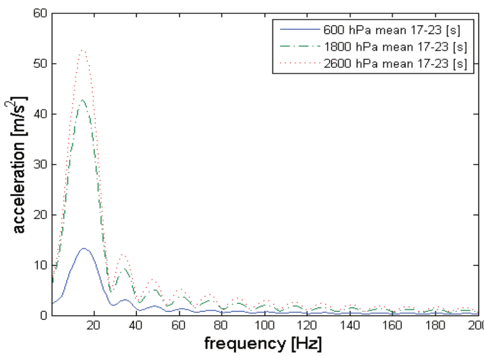


b) 22-26 s

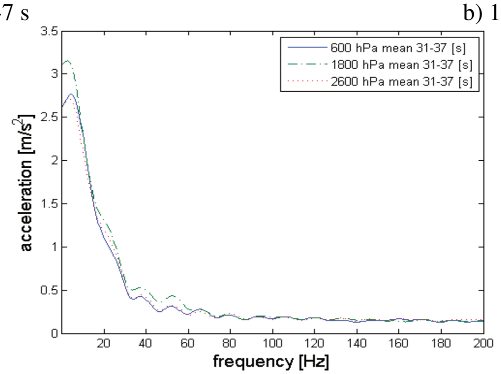
Fig. 10.18. Frequency function of average vibration in time periods: floor under rear right passenger’s feet



a) 1-7 s

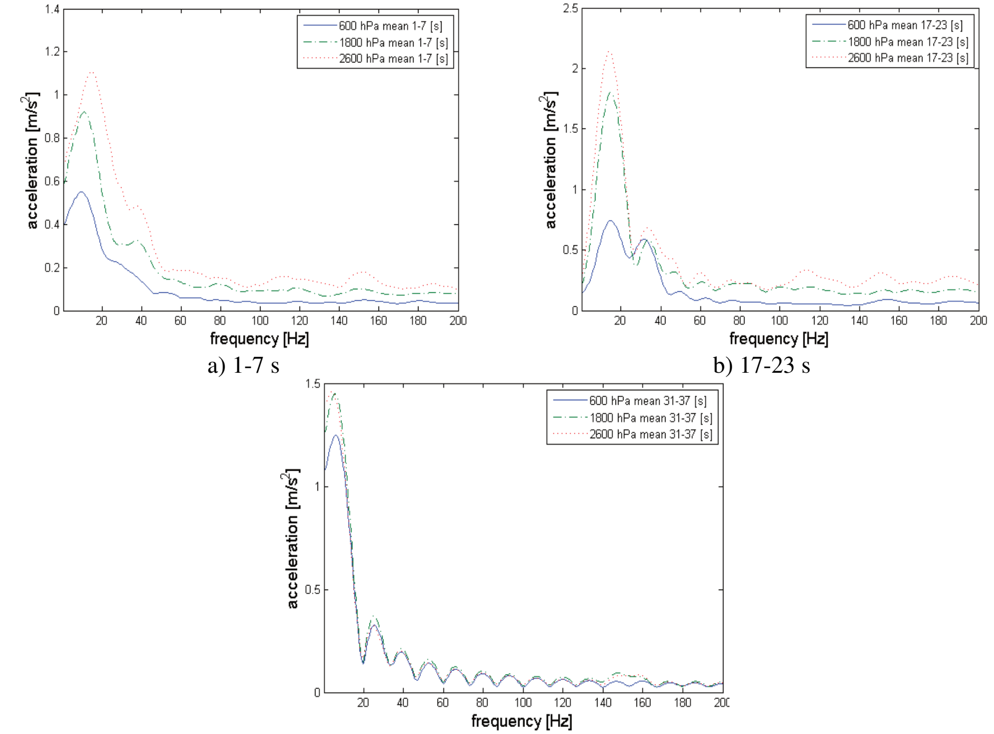


b) 17-23 s



c) 31-37 s

Fig. 10.19. Frequency function of average vibration in time periods: suspension arm

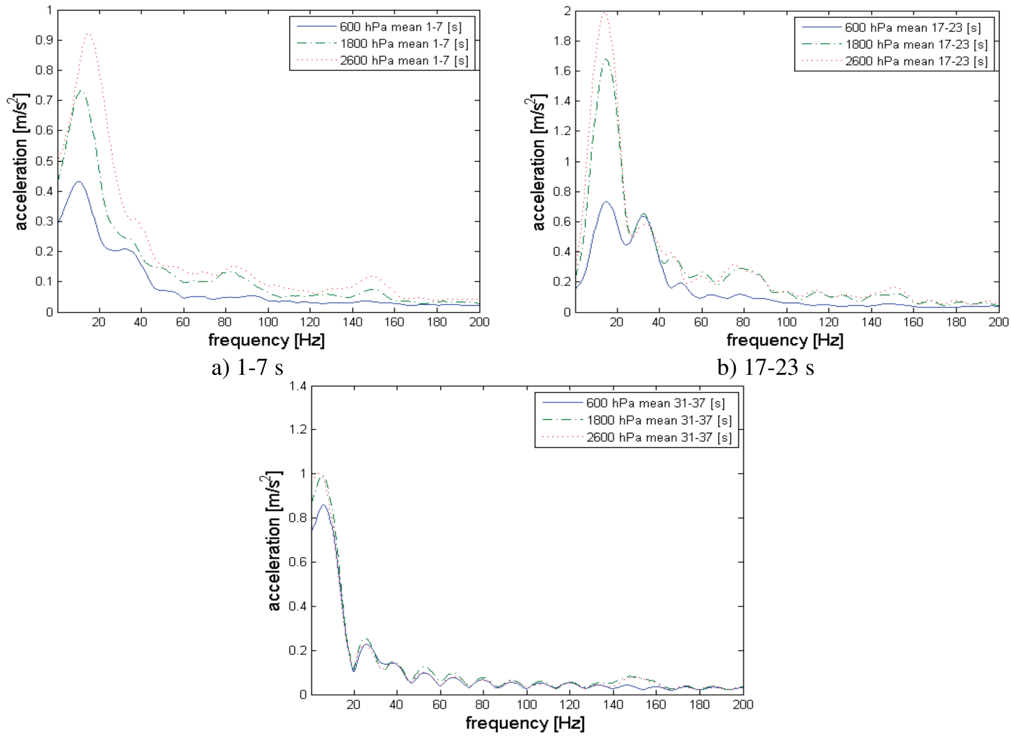


a) 1-7 s

b) 17-23 s

c) 31-37 s

Fig. 10.20. Frequency function of average vibration in time periods: upper mounting of shock absorber

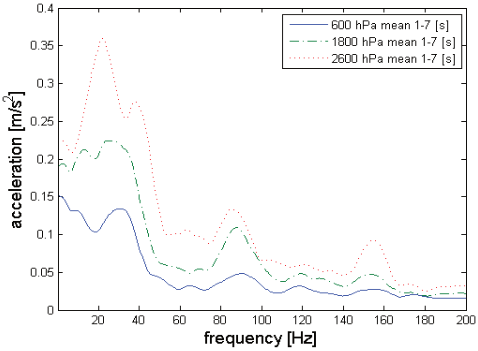


a) 1-7 s

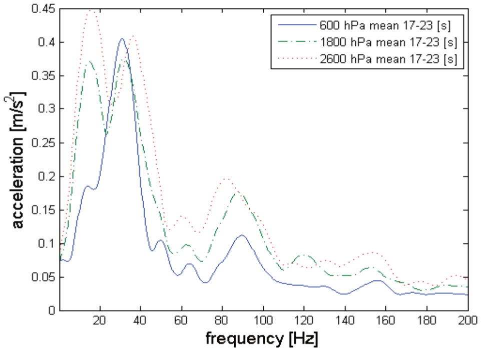
b) 17-23 s

c) 31-37 s

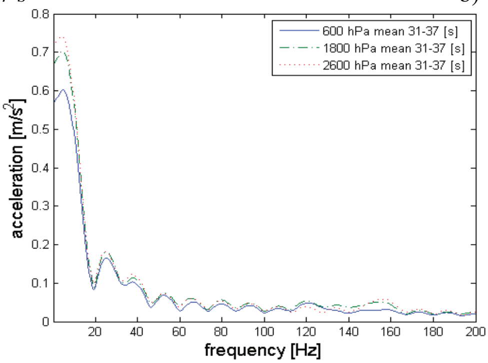
Fig. 10.21. Frequency function of average vibration in time periods: floor under driver's feet



a) 1-7 s

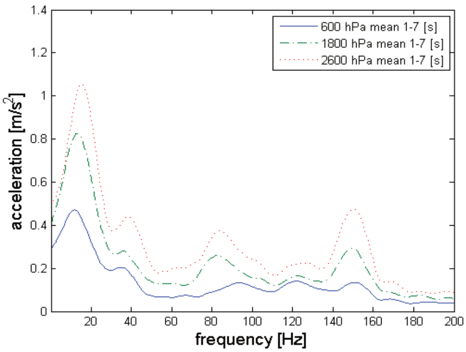


b) 17-23 s

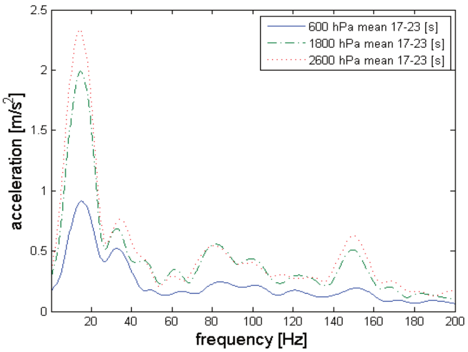


c) 31-37 s

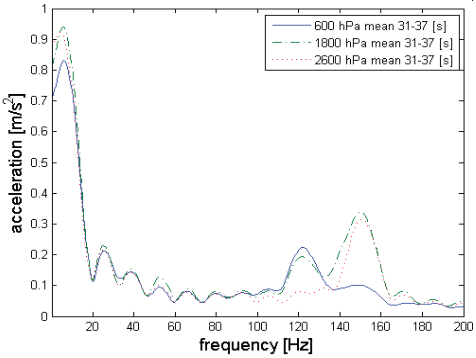
Fig. 10.22. Frequency function of average vibration in time periods: floor under front passenger's feet



a) 1-7 s

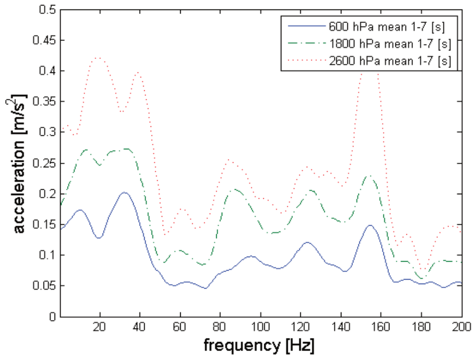


b) 17-23 s

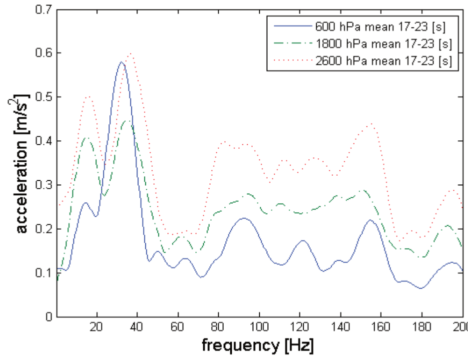


c) 31-37 s

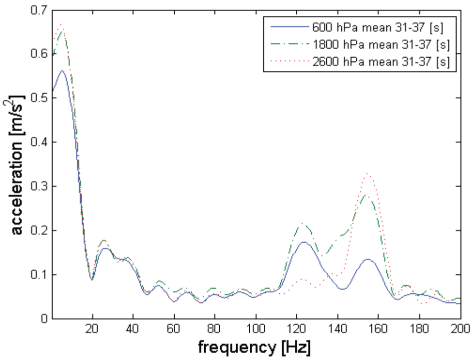
Fig. 10.23. Frequency function of average vibration in time periods: floor under rear left passenger's feet



a) 1-7 s



b) 17-23 s



c) 31-37 s

Fig. 10.24. Frequency function of average vibration in time periods: floor under rear right passenger's feet

The analysis of the technical condition of suspension elements and vehicle's operating parameters influence on the vibration in terms of human perception and exposure require identification of frequency component carrying most of the vibration energy. For the motor vehicle vibration the highest energy dissipation can be observed during time of passing thru resonance of unsprung masses. Thus the frequency distribution of the vibration in defined time period has to be analyzed. The developed functions S_t, S_{Tavr} represent dominant dynamics components of vibration excited during most vibro-activity time of exposure and function of average value of time period vibration in frequency domain allow identify frequency components.

The results confirm good sensitivity of the function on the damping of shock absorber and pressure in tire. The course of the function allows to identify dominant frequency components. The most energy dissipation is result of the vibration in unsprung masses resonance (12-18 Hz) but some other frequencies represent dynamics of the vibration with high energy (i.e. 160 Hz).