8. Identification of vehicle vibration's structure in research on the influence of changes in the technical condition of suspension elements and of the vehicle operating parameters on the vibration distribution in a vehicle structure

The identification of sources and propagation's path of dynamics phenomena requires analysis in terms and conditions which are determining the course, modes and perception of the phenomena. The vibration has to be considered in terms of amplitude, time and frequency. The evaluation of impact of chosen factors on vibration occurring in motor vehicles requires wide scope of amplitude, time and frequency characteristics analysis. The previous chapter presents results of analysis of vibration distribution separately in time and frequency domains. It represents the amplitude-time and amplitude-frequency characteristics of vibration.

The properties of human vibration perception, discussed in Chapter 2, require observation of distribution of vibration in time and frequency domains for the analysis of vibration phenomena in mean of transport. Thus it is very helpful to identify structure of the vibration as correlated time-frequency distribution. Such an approach enables the analysis of exposure to vibration. This presentation of vibration's structure enables identification of time of exposure to chosen vibration dynamics. This approach allows precise evaluation of exposure to vibration correlated to natural vibration of human organs.

In the scope of engineering applications the presented approach allows designing and developing of elements and systems dedicated to absorb or isolate of vibration in chosen frequency bands.

8.1. Application of time-frequency representation methods for determination of vibration structure

Signal analysis addresses the problem of extracting information from registered signal and converting it into a recognizable form. The time courses recorded provide information on the phenomenon in question, however, in order to extract it, application of the appropriate mathematical method proving is necessary. The results obtained belong to a group of non-stationary signals the analysis of which enforces one to apply time-frequency methods. For the nonstationary signal, when the components of the signal changes with time, the representation of the signal in frequency domain become less useful. Simultaneous extraction of information concerning the time-frequency structure of a signal being analysed is possible owing to 2-dimensional transforms. To achieve frequency representation that includes dependence on time the double arguments function is needed, i.e. time-frequency representation (TFR).

The first attempt to develop such a function was carried out by Gabor in 1946 [87]. His approach can be considered as special case of the Short-Time Fourier Transform (STFT), expressed as:

$$S(\omega,b)=\int_{-\infty}^{+\infty}x(t)\omega_{a,b}(t)dt=\int_{-\infty}^{+\infty}x(t)g(t-b)^{-i\omega t}dt, \tag{8.1}$$

where: b – window displacement, ω – analysing frequencies, $g(t-b)=const$ – constant width of successively analysed window.

The $g(t-b)$ window is typical chose as the Gaussian function or Hann function. The good properties of this window function occur from smoothly and symmetrically falls to zero around the time $t=0$ and is centered about $t=b$. The STFT segmenting the signal into narrow time intervals (i.e., narrow enough to be considered stationary) and takes the Fourier transform of each segment. Thus each Fourier transform provides the spectral information of a separate time-slice of the signal, providing simultaneous time and frequency information. Some disadvantage of STFT is a constant width of the window. If the window is too long transformation providing excellent frequency localization, but no time information. When the window is too short transformation gives the time signal back, with a phase factor, providing excellent time localization but no frequency information.

Simultaneous extraction of information concerning the time-frequency structure of a signal being analysed is possible owing to a wavelet transform. It is so because the wavelet function applied in this transformation can be extended or shortened. Narrow wavelets make it possible to analyse high-frequency components of a signal, and appropriately long base functions reveal its slowly-variable properties. The template role is performed by basic wavelet $\psi(t)$. The wavelet functions as a transformation kernel. A single wavelet is used in the given transformation, however, due to modification of scale coefficient a and modification coefficient b, it forms what is referred to as a wavelet family. A wavelet transformation of signal $x(t)$ may be defined as follows:

$$WT_x(a,b)=\frac{1}{\sqrt{a}}\int_{-\infty}^{\infty}x(t)\,\Psi\left(\frac{t-b}{a}\right)dt, \tag{8.2}$$

where: $\Psi(t)$ – wavelet family, $\Psi((t-b)/a)$ – transformation kernel, a – scaling parameter effecting frequency change $a\in R^{+}/0 \wedge a\sim 1/f$, f – frequency, $1/\sqrt{a}$ – wavelet standardized constant, b – shift parameter locating the wavelet position against time axis $b\in R$.

The wavelet transform represents the correlation between the signal analysed and function $\Psi(t)$ having been appropriately scaled. The very idea of wavelet transformation is the decomposition of signal $x(t)$ into wavelet coefficients $WT_x(a,b)$ by application of the base function. As a result of such a transformation, one obtains coefficients being functions of scale and time. By altering the parameters of scale a and time shift b, one may obtain the time-frequency distribution. The base function of the wavelet transformation is subject to the operations of scaling and shifting which makes it possible to obtain wavelets of various lengths of decay time and centre frequencies. The best results are obtained by this method when wavelets adjusted in shape to the relevant signal features are used.

The Wigner-Ville distribution approach is based on the use of the autocorrelation function for calculating the power spectrum. To construct the autocorrelation function, the signal is compared to itself for all possible relative shifts, or lags. The Wigner-Ville uses a variation of the autocorrelation function where time remains in the result, called instantaneous autocorrelation function. The Wigner-Ville Distribution (WVD) is defined as:

$$WVD_{xx}(\theta,\tau)=\int x^{*}\left(t-\frac{\tau}{2}\right)x\left(t+\frac{\tau}{2}\right)e^{-j2\pi\theta t}\,dt, \tag{8.3}$$

where: x^{*} – represents the complex conjugate of the signal x, τ – time shift, θ – frequency shift.

The analytic associate $x(t)$ of a signal $s(t)$ is defined such that $x(t)\equiv s(t)+iH[s(t)]$, where $H[s(t)]$ is the Hilbert Transform of the signal $s(t)$. In most cases, the TFR techniques are applied to the analytic associates of real signals unless noted otherwise – in particular, $x(t)$ is generally the complex-valued analytic associate of some real-valued time signal of interest. WVD is obtained by comparing the information of the signal with its own information at other times and frequencies. The WVD is a quadratic TFR, and most other TFR methods (including the spectrogram, i.e. STFT and the scalogram, i.e. WT) can be derived from the WVD, with a suitable choice of smoothing factors.

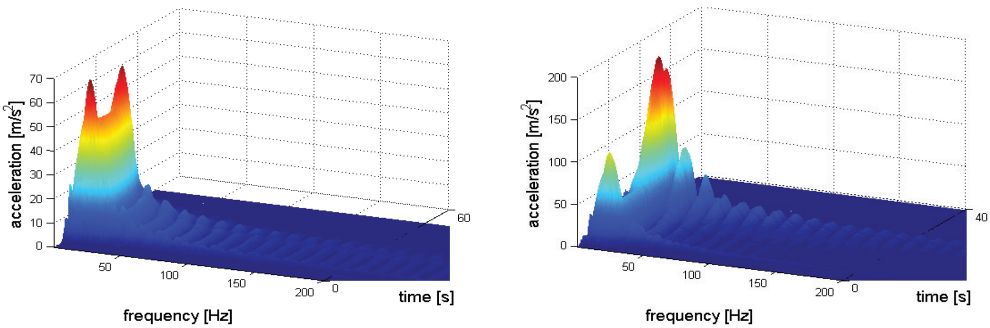
Wigner distribution was first introduced by E. Wigner in the context of quantum mechanics (Wigner, 1932), and later independently developed by J. Ville who applied the same transformation to signal processing and spectral analysis (Ville, 1948) [30, 194, 199].

8.2. Analysis of time structure of vibration in determined frequency bands

For the research results analysis on influence of suspension's technical condition and vehicle's operating parameters on structure of occurring vibration the STFT of the signals were calculated. The reason of choosing the STFT was time consumption of the analysis process, because utility and applicability requirements. The 3-D formats of absolute values of STFT transformation of vibration are shown in Figs. 8.1-8.10. The distribution in time of vibration energy for next frequencies can be observed.

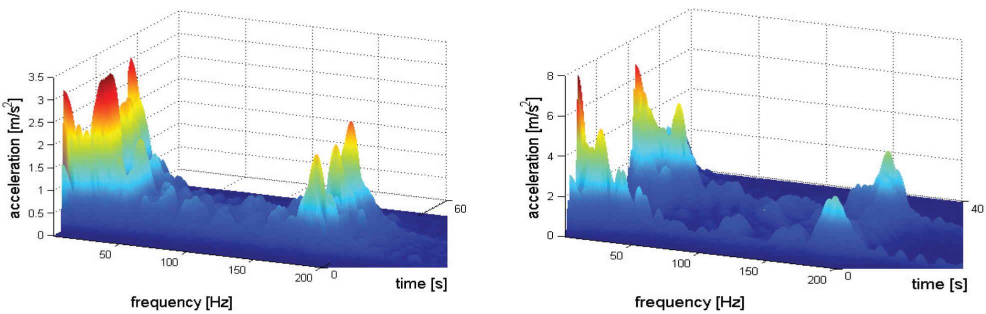
8.2.1. Influence of the damping of shock absorber on structure of vibration in vehicle construction

The STFT transformation of vibration registered during research on vehicle with build in shock absorbers with 100 % and 50 % of liquid volume are shown in figures below. It shows that for the shock absorber with 50 % of liquid the vibration energy become more centered and occurred in nonstationary parts of the signal.



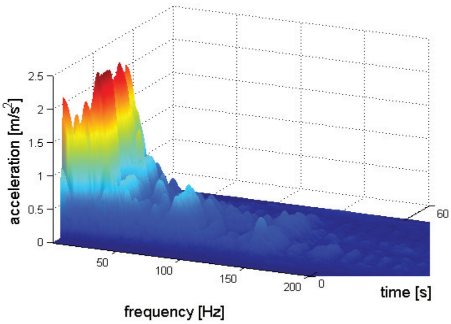
a) Shock absorber with 100 % of liquid volume b) Shock absorber with 50 % of liquid volume

Fig. 8.1. Time-frequency distribution of the vibration of suspension arm

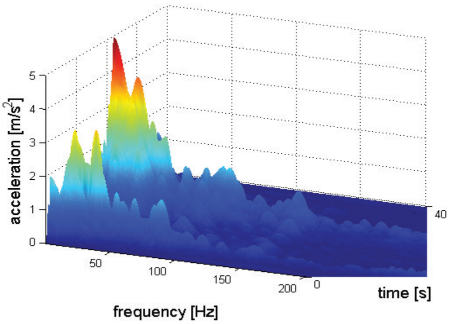


a) Shock absorber with 100 % of liquid volume b) Shock absorber with 50 % of liquid volume

Fig. 8.2. Time-frequency distribution of the vibration of upper mounting of shock absorber

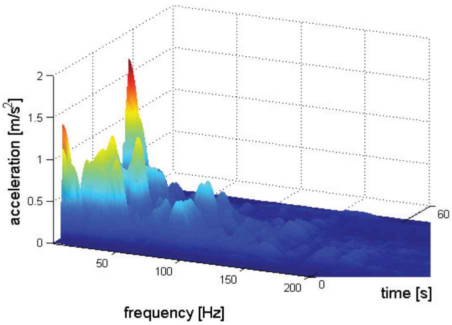


a) Shock absorber with 100 % of liquid volume

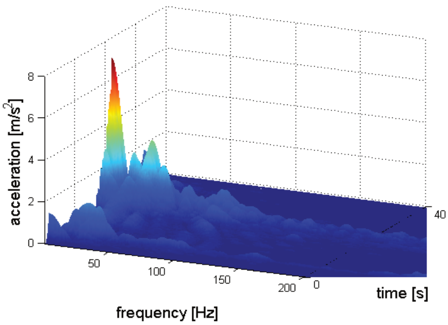


b) Shock absorber with 50 % of liquid volume

Fig. 8.3. Time-frequency distribution of the vibration of floor under driver's feet

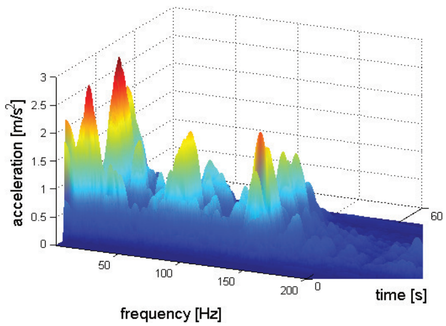


a) Shock absorber with 100 % of liquid volume

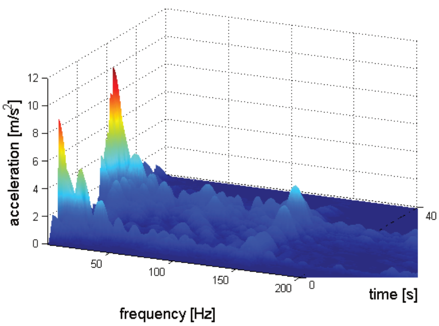


b) Shock absorber with 50 % of liquid volume

Fig. 8.4. Time-frequency distribution of the vibration of floor under front passenger's feet

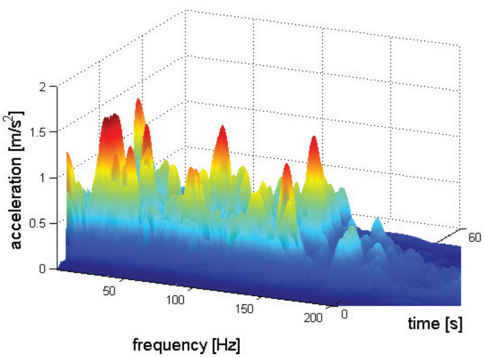


a) Shock absorber with 100 % of liquid volume

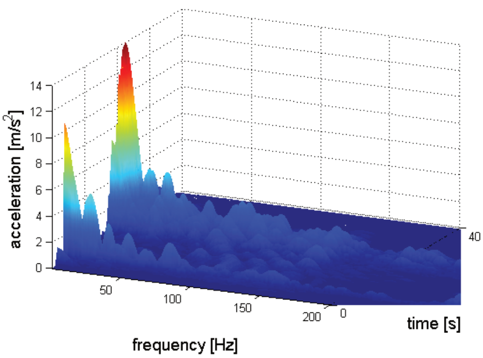


b) Shock absorber with 50 % of liquid volume

Fig. 8.5. Time-frequency distribution of the vibration of floor under rear left passenger's feet



a) Shock absorber with 100 % of liquid volume



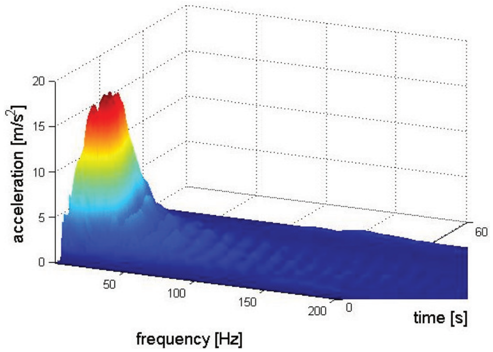
b) Shock absorber with 50 % of liquid volume

Fig. 8.6. Time-frequency distribution of the vibration of floor under rear right passenger's feet

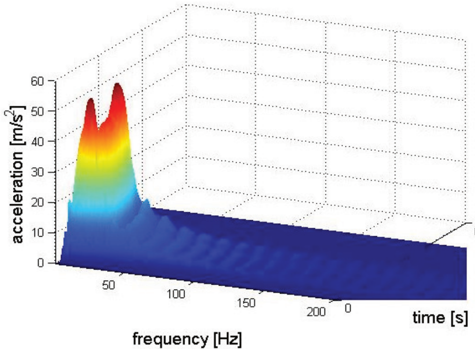
The Figs. 8.1 and 8.2 present time-frequency structure of the vibration of the suspension arm and upper mounting of shock absorber and the floor pan under driver's feet. The Figs. 8.3-8.6 show results of STFT of vibration registered on the floor panel under passenger's feet.

8.2.2. Influence of the pressure in tires on structure of vibration in vehicle construction

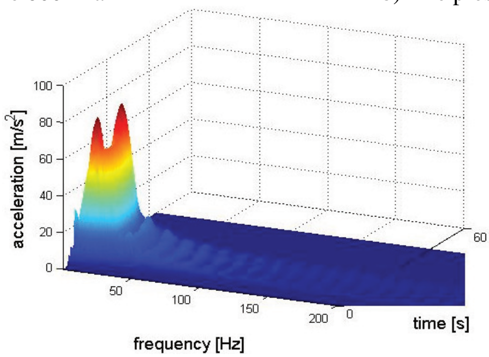
Figs. 8.7-8.12 present STFT transformation of vibration registered during research on vehicle with different pressure in tires. The results shows frequencies of the vibration occurring due to the increase of the pressure in tires. The number of time periods and frequencies of the vibration grows with the increase of the tire pressure.



a) Tire pressure 600 hPa



b) Tire pressure 1800 hPa

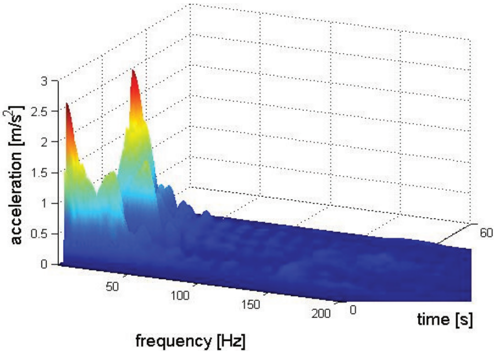


c) Tire pressure 2600 hPa

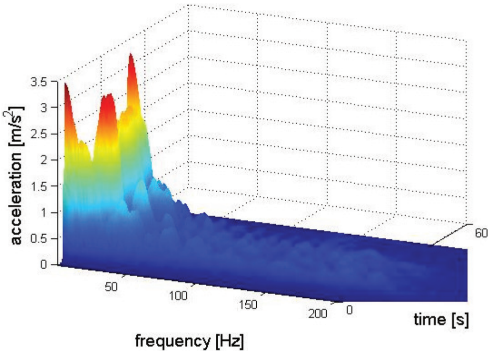
Fig. 8.7. Time-frequency distribution of the vibration of suspension arm

Exposure to vibration in means of transport depends on many factors. For the passengers it is important what type of vibration penetrates to the human body via vehicle construction or elements. For the perception properties as type of vibration we can consider the value, dynamics and exposure time of chosen frequency components of the vibration. The possibilities of simultaneous observation of distribution of signal in time and frequency domains are reached by the time-frequency representation (TFR) of the signal. There are many mathematical methods and techniques for transformation signal into TFR, mainly based on the transformation described in Chapter 8.2.

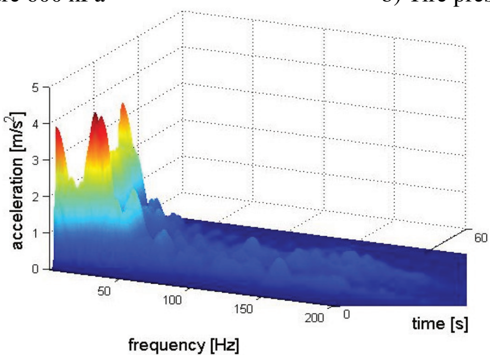
The chapter addresses results of analysis of application of one of the TFR techniques to the identification of structure of vibration. The possibilities of identification of characteristics components of vibration structure and sensitivity on the changes in mechanical system parameters have been investigated on the results of the research on influence of technical condition of suspension and operating parameters of the vehicle. The 3-D (amplitude, time, frequency) structure of the vibration obtained in result of STFT allow proper identification of the vibration and propagation into vehicle construction.



a) Tire pressure 600 hPa

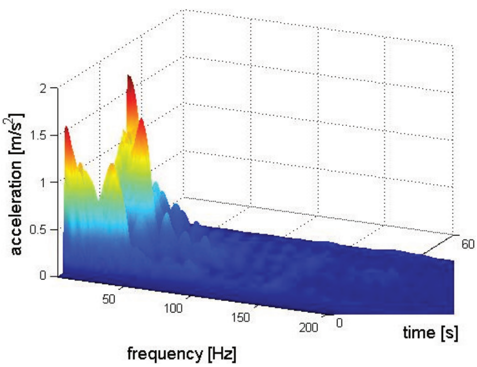


b) Tire pressure 1800 hPa

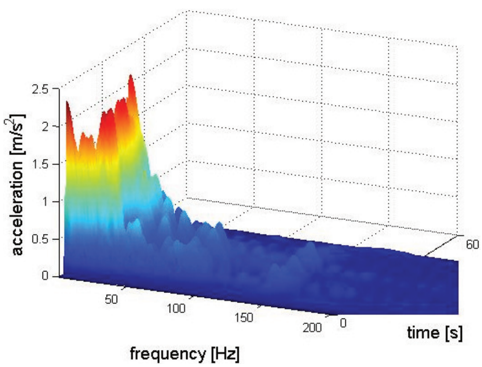


c) Tire pressure 2600 hPa

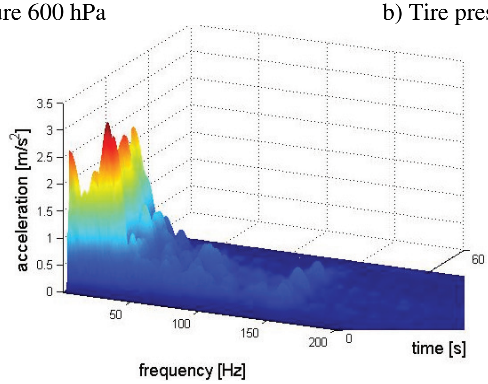
Fig. 8.8. Time-frequency distribution of the vibration of upper mounting of shock absorber



a) Tire pressure 600 hPa

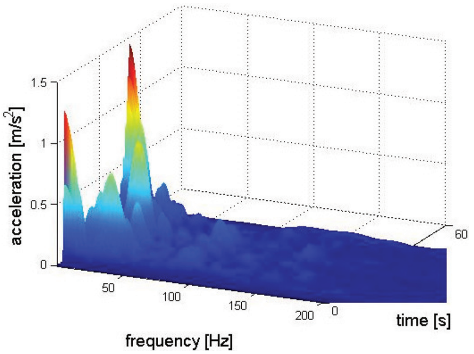


b) Tire pressure 1800 hPa

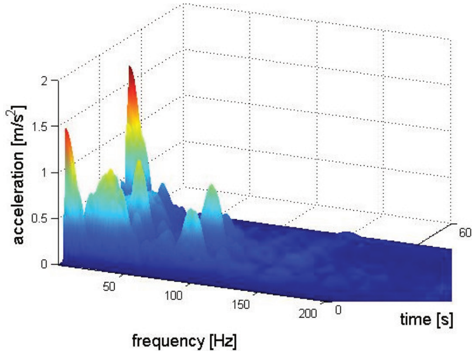


c) Tire pressure 2600 hPa

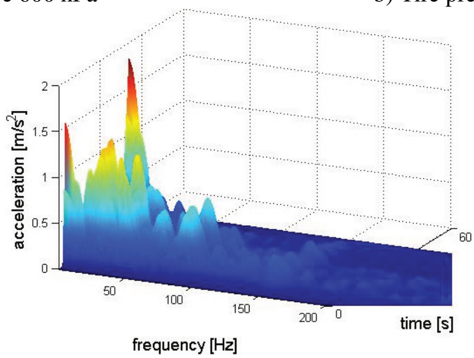
Fig. 8.9. Time-frequency distribution of the vibration of floor under driver's feet



a) Tire pressure 600 hPa

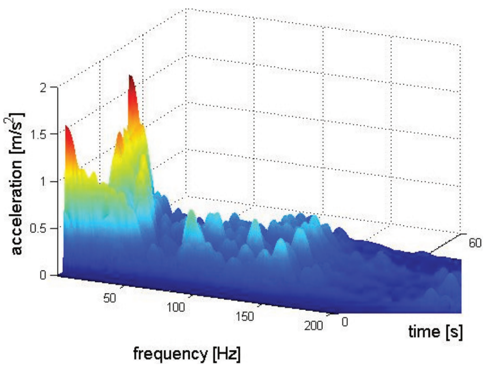


b) Tire pressure 1800 hPa

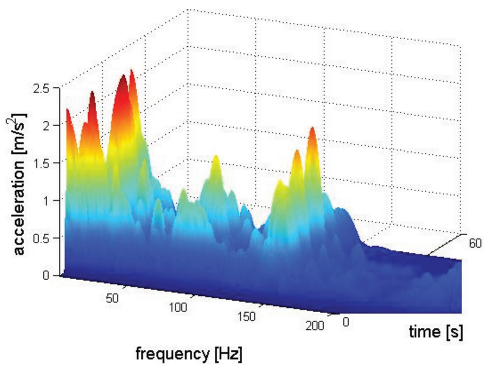


c) Tire pressure 2600 hPa

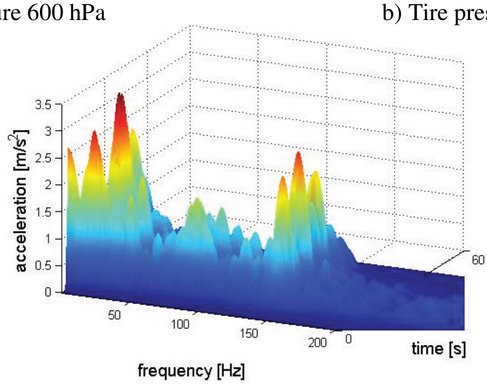
Fig. 8.10. Time-frequency distribution of the vibration of floor under front passenger's feet



a) Tire pressure 600 hPa

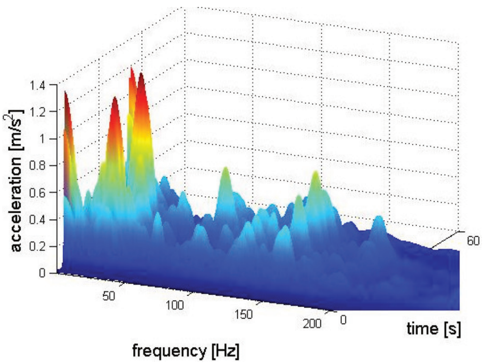


b) Tire pressure 1800 hPa

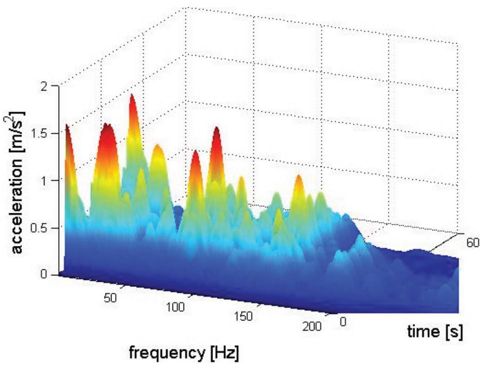


c) Tire pressure 2600 hPa

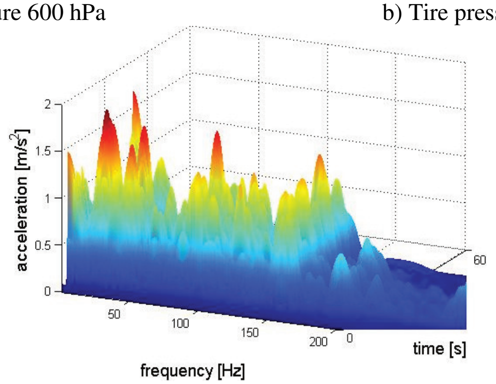
Fig. 8.11. Time-frequency distribution of the vibration of floor under rear left passenger's feet



a) Tire pressure 600 hPa



b) Tire pressure 1800 hPa



c) Tire pressure 2600 hPa

Fig. 8.12. Time-frequency distribution of the vibration of floor under rear right passenger's feet

The influence of the damping of shock absorber can be observed in vibration's structure, as an increase of the vibration energy. The time-frequency distribution of the vibration allows localization of window with highest increase of energy generated during passing by resonance frequency of unsprung masses in the time period of coasting of exciter machine. The structure of the vibration registered under study of influence of the pressure in tires shows increase of energy of the vibration due to increase of pressure in tires. The structures of the vibration are different than in results of damping influence. The total energy of the vibration is lower and there are many more higher frequencies components in the signals. The increase of the vibration can also be observed for time period of constant excitation (constant frequency).