14. Influence of gear position in transmission gearbox on vibration

What is required in order to consider the engine as a source of vibrations in a moving vehicle is an analysis of the impact exerted by other mechanisms of the power transmission system on the vibration propagation from the source. And bearing the vibroacoustic emission in mind, one of the most crucial mechanisms is the transmission. There is real abundance of publications discussing the problems of gear transmission vibrations [20, 82, 130, 159, 167, 185, 189, 201, 212]. Propagation paths of the vibrations generated by the engine and transmission operation may be convergent or divergent, all depending on the system of mounting and coupling of the power transmission system elements. In order to analyse the vehicle vibrations from the perspective of their impact on passengers, it is not required to distinguish between individual propagation paths. It was assumed that the propagation paths were convergent, whereas the vibrations recorded at locations where they penetrated the human organism were considered as a random dynamic response of the vehicle structure to numerous input functions of vibration sources.

14.1. Gearbox vibration

The gearbox is a source of vibration and, consequently, noise. Except for bearing fatal defects or extreme structure-resonance amplification, gears are the main sources of high frequency vibration and noise, even in newly built units. Gears, by their inherent nature, cause vibrations due to the large pressure which occurs between the meshing teeth when gears transmit power. Meshing of gears involves changes in the magnitude, the position and the direction of large concentrated loads acting on the contacting gear teeth, which as a result causes vibrations. The main parts of the gearbox are the gears, shafts, bearings, housing, and the outside of the gearbox clutches and couplings. Gears are machine elements that transmit motion by means of successively engaging teeth [185].

A simple gear train (a pair of meshing gears extended optionally by idler gears) is characterized by only one toothmeshing frequency. All the basic spectrum components are usually broken down into a combination of the following effects [188]:

– low harmonics of the shaft speed originating from unbalance, misalignments, a bent shaft, and resulting in low frequency vibration;

– harmonics of the base toothmeshing frequency and their sidebands due to the modulation effects that are well audible, the vibration of the geared axis systems originated from parametric, self-excitation due to the time variation of tooth-contact stiffness in the mesh cycle, the inaccuracy of gears in mesh, and non-uniform load and rotational speed;

– ghost components due to errors in the teeth of the index wheel of the gear cutting machine, especially gear grinding machines employing the continuous shift grinding method that results in high frequency due to the large number of index-wheel teeth, these ghost components disappear after running-in;

– components originating from faults in rolling-element bearings usually of the low level noise except for fatal bearing faults as the cracking or pitting of the inner or outer race or of the rolling element itself.

Except for the frequency spectrum components originating from the rolling bearings, the frequency of the components, which are associated with the meshing gears, is an integer multiple of the shaft rotational frequency. There are subharmonic components as well. These components are excited at the half of the teeth resonant frequency in high-speed units (thousands RPM) due to the non-linearity of tooth stiffness.

14.2. Research method

The aim of the investigation was to find the influence of the gear position (gear ratio) on exposure to whole-body vibration of driver. The scope of the research included measurements of vibration for constant engine rotational speed and different gear positions. The car was set on special laboratory stand to allow start the power transmission by the engine and gearbox into lifted drive wheels. The experiments were conducted for the engine rotational speed of 1500 rpm and successive gear positions: neutral, first-speed gearwheel, second-speed gearwheel, third-speed gearwheel, fourth-speed gearwheel, fifth-speed gearwheel and reverse gear.

14.3. Research result

The vibration signals were transformed into frequency domain and TFR as STFT transformation. The collection of obtained results in three orthogonal axes are shown in Figs. 14.1-14.9.

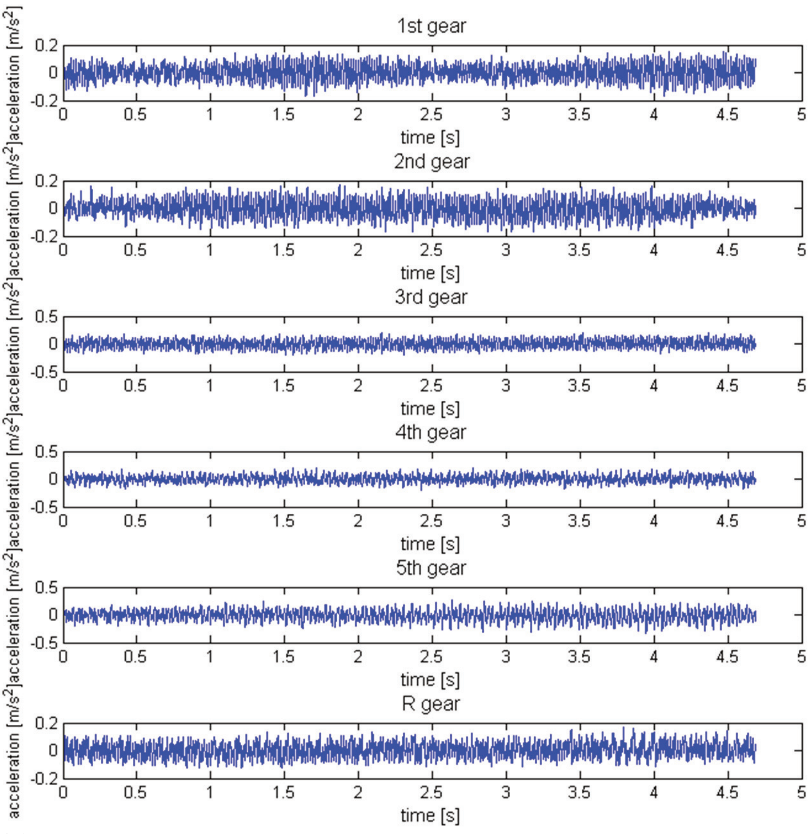

Fig. 14.1. The collection of longitudinal vibration signals measured on the floor panel in location of driver feet for different gear position

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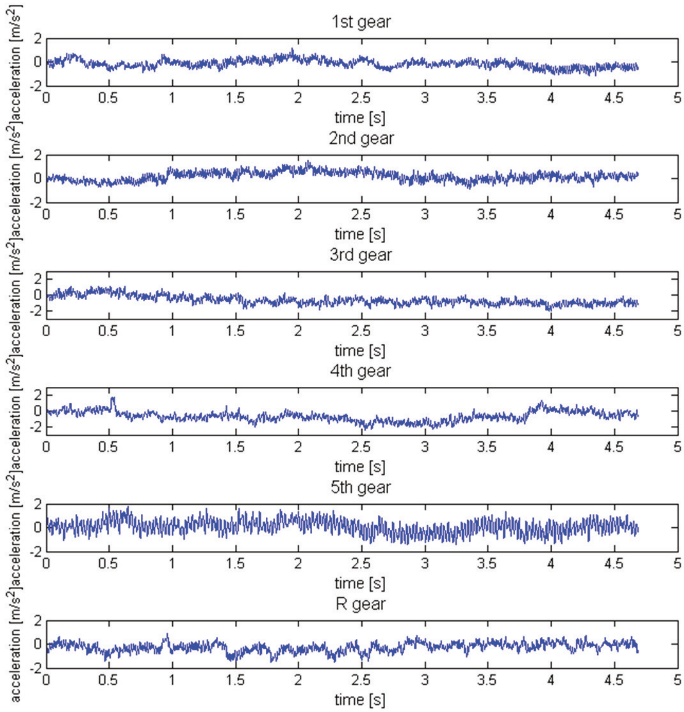


Fig. 14.2. The collection of lateral vibration signals measured on the floor panel in location of driver feet for different gear position

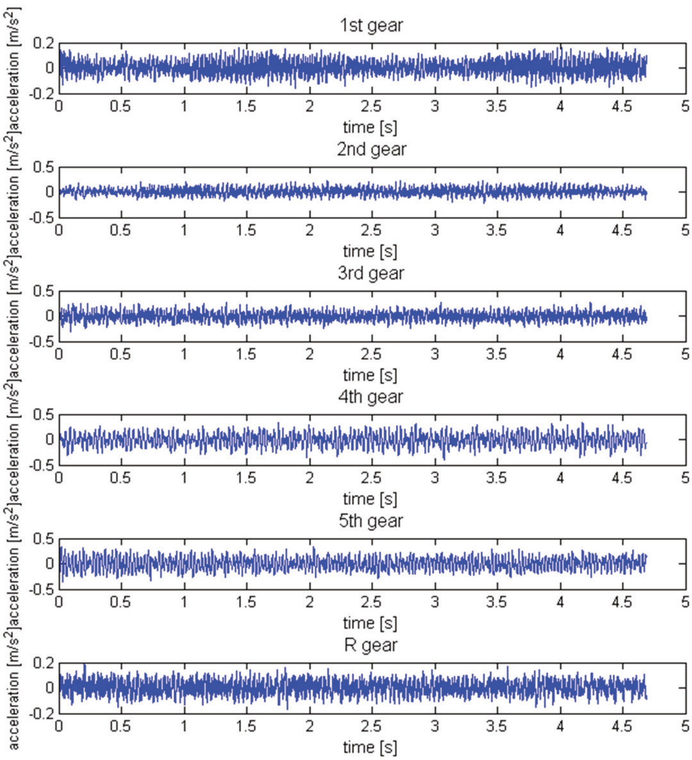


Fig. 14.3. The collection of vertical vibration signals measured on the floor panel in location of driver feet for different gear position

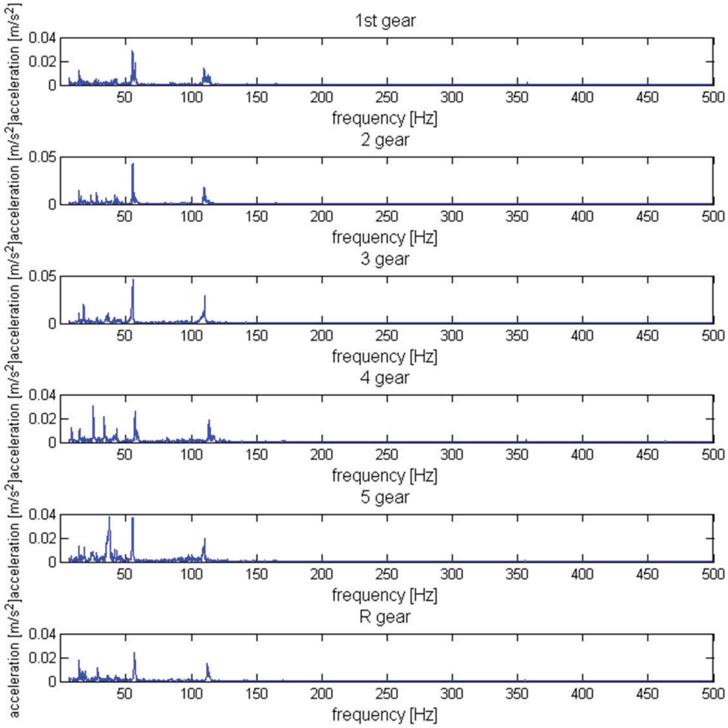


Fig. 14.4. The collection of spectrums of longitudinal vibration signals measured on the floor panel in location of driver feet for different gear position

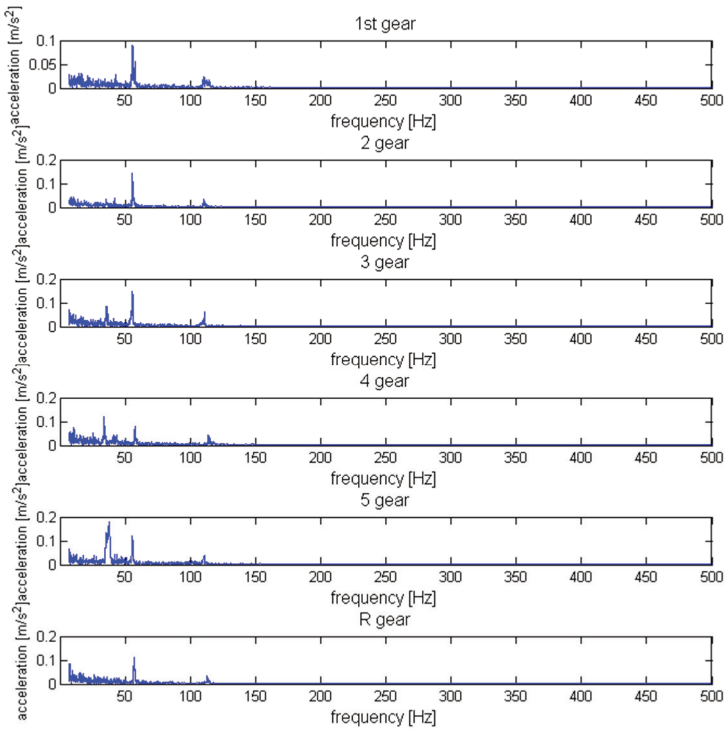


Fig. 14.5. The collection of spectrums of lateral vibration signals measured on the floor panel in location of driver feet for different gear position

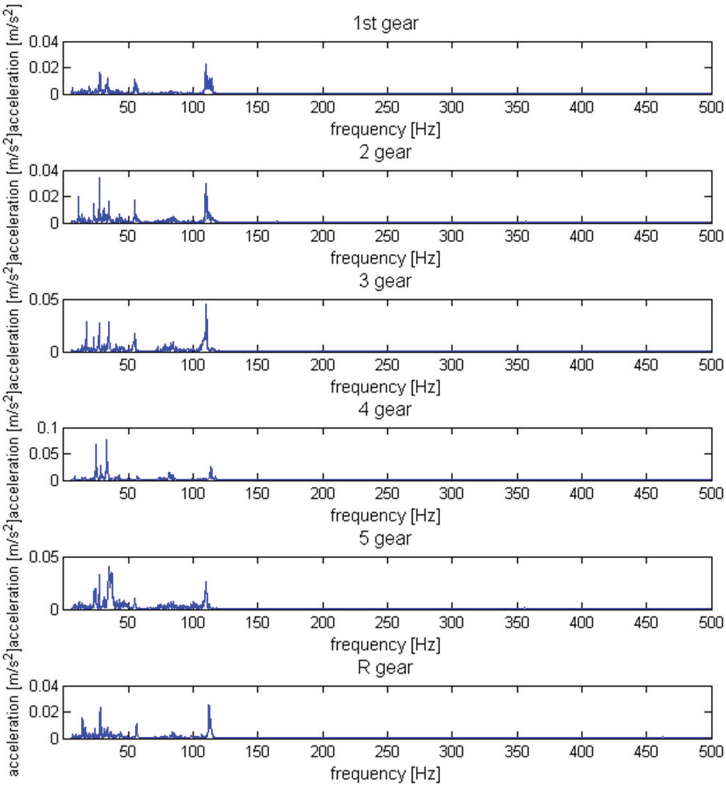
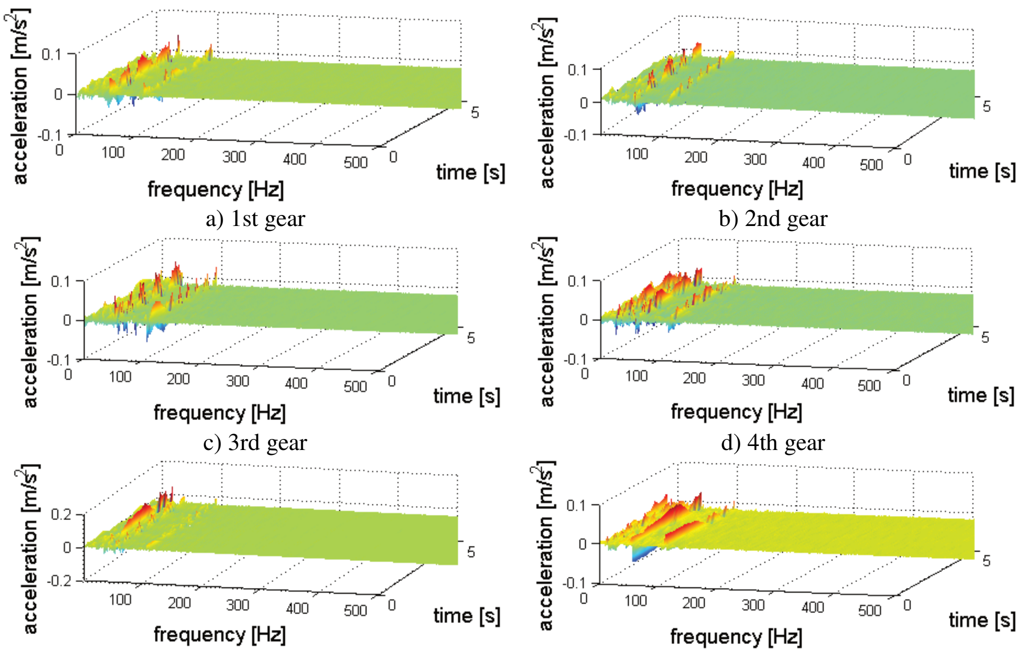


Fig. 14.6. The collection of spectrums of vertical vibration signals measured on the floor panel in location of driver feet for different gear position

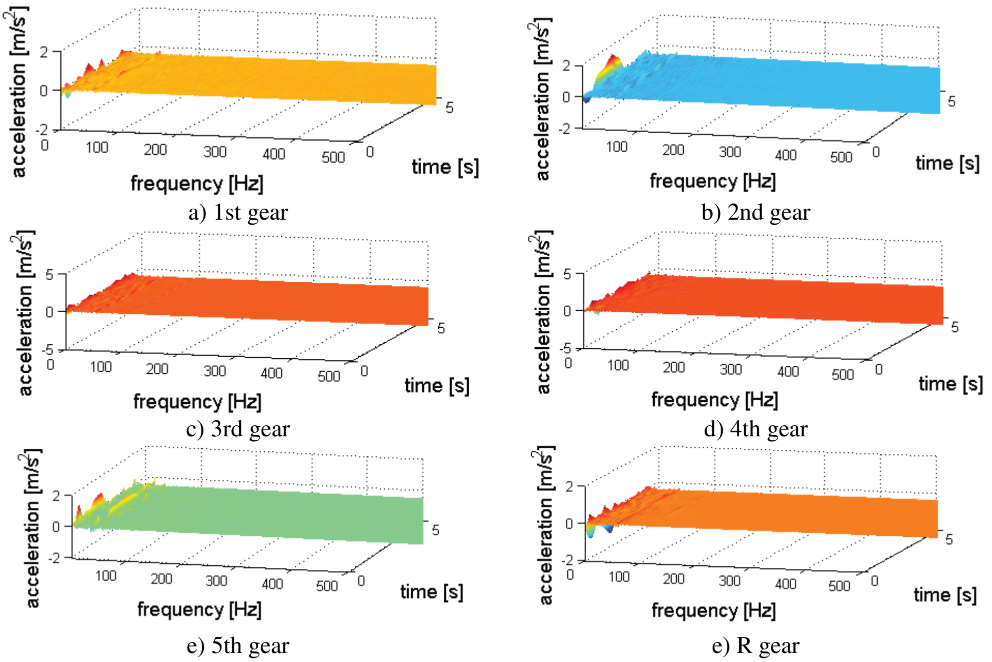


a) 1st gear b) 2nd gear

c) 3rd gear d) 4th gear

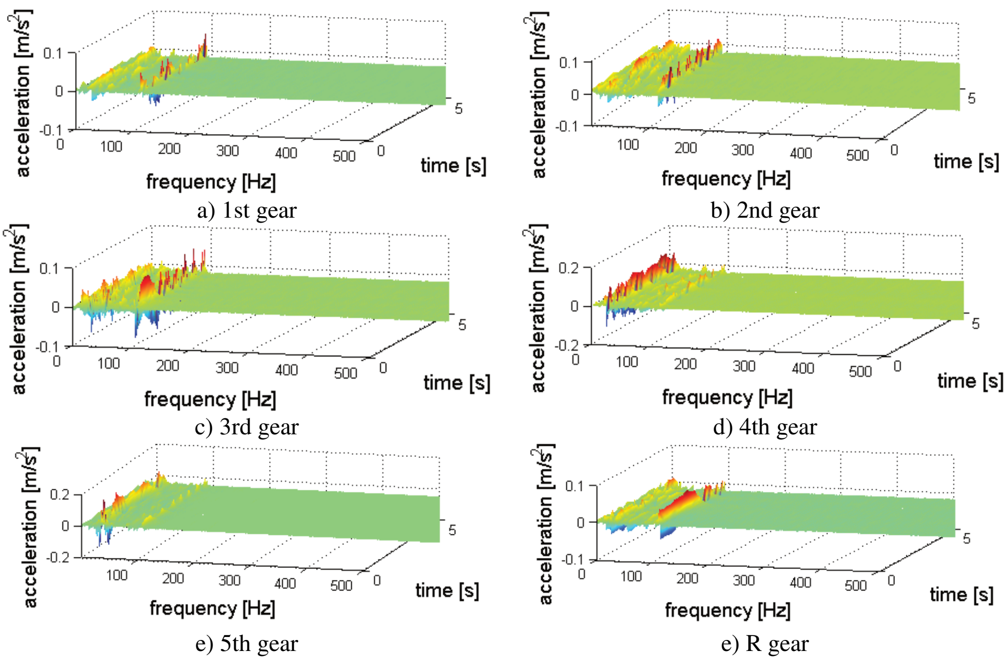
e) 5th gear e) R gear

Fig. 14.7. The collection of TFR of longitudinal vibration signals measured on the floor panel in location of driver feet for different gear position (time window 0.25 s, resolution 0.4884 Hz)



a) 1st gear
b) 2nd gear
c) 3rd gear
d) 4th gear
e) 5th gear
e) R gear

Fig. 14.8. The collection of TFR of lateral vibration signals measured on the floor panel in location of driver feet for different gear position (time window 0.25 s, resolution 0.4884 Hz)



a) 1st gear
b) 2nd gear
c) 3rd gear
d) 4th gear
e) 5th gear
e) R gear

Fig. 14.9. The collection of TFR of vertical vibration signals measured on the floor panel in location of driver feet for different gear position (time window 0.25 s, resolution 0.4884 Hz)

For the purpose of analysis of influence of gear position in transmission gearbox on vibration the estimators, defined in previous chapter, were compared. Fig. 14.10 present the distribution of these estimators with values for neutral gear.

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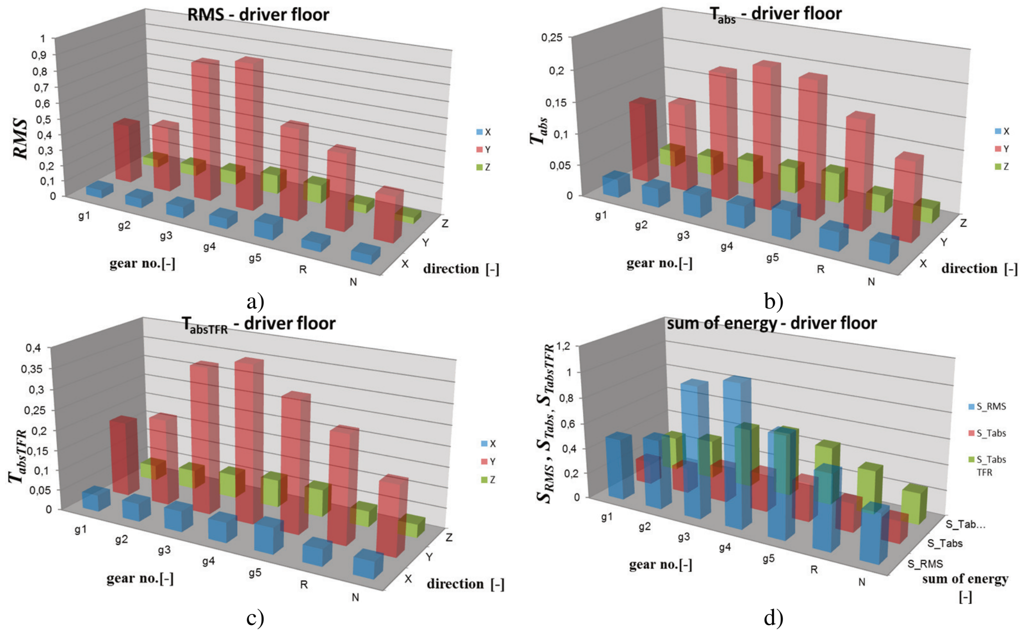


Fig. 14.10. The distribution of directional estimators: a) RMS, b) T_{abs}, c) T_{absTFR} and d) total energy estimators S_{RMS}, S_{Tabs} and $S_{TabsTFR}$ for different gear position (vibration signals measured on the floor panel in location of driver feet)

14.4. Identification of vibration components caused by the gearbox

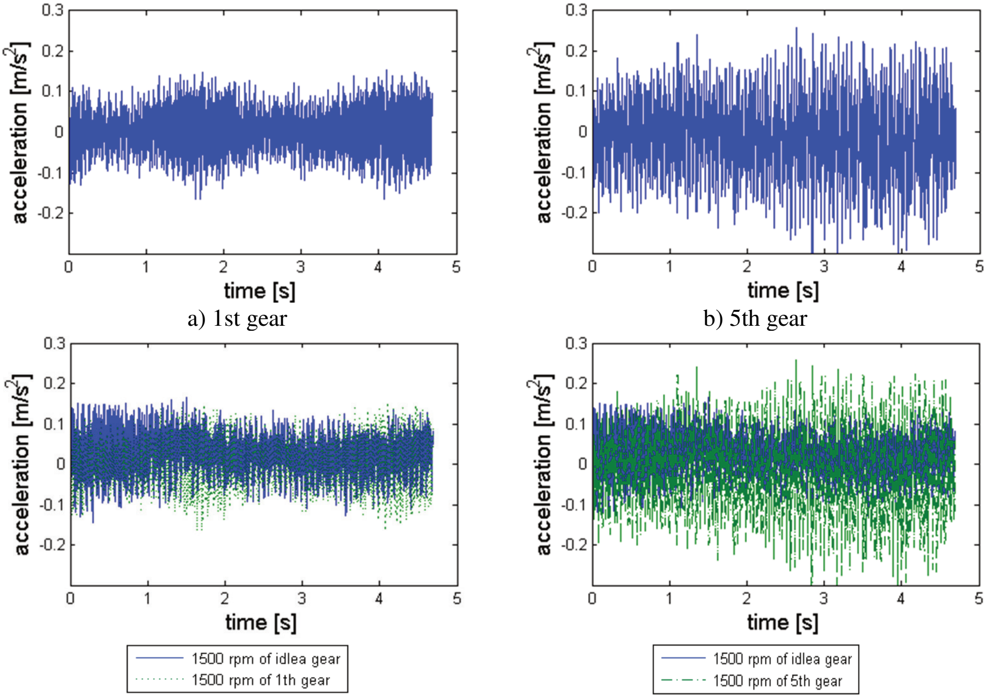
The purpose of the analysis was to identify vibration components caused due to the large pressure which occurs between the meshing teeth when gears transmit power. For these goal the time domain vibration was compared, which enables observation of vibration energy changes for the neutral idle gear and first-speed or fifth-speed gear position (Figs. 14.11-14.13).

The dynamic components can be identified by the comparison of spectrums and differential spectrum of neutral gear and running gear vibration (Figs. 14.14-14.16), expressed from equation:

$$F_d(\omega) = \left|F_g(\omega) - F_n(\omega)\right|, \tag{14.1}$$

where: $F_g(\omega)$ – Fourier transform of running gear vibration, $F_n(\omega)$ – Fourier transform of neutral gear vibration.

For the analysis of structure of vibration the TFR of the vibration of first-speed and fifth-speed gear and neutral idle gear are presented in Figs. 14.17-14.19.



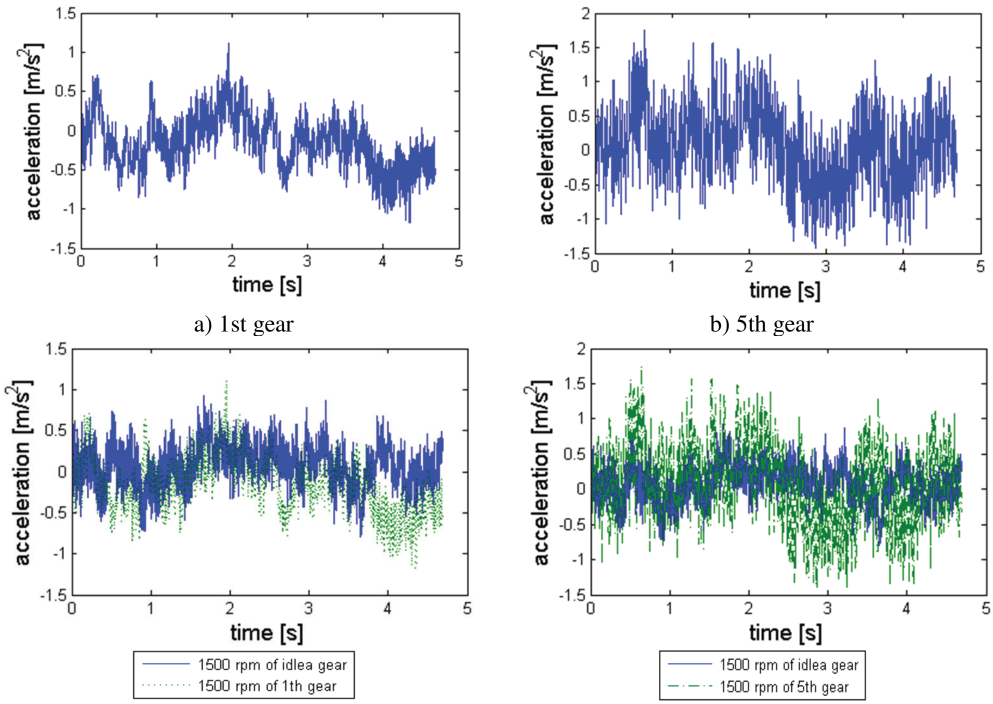
a) 1st gear

b) 5th gear

c) Idle gear vs 1st gear

d) Idle gear vs 5th gear

Fig. 14.11. The comparison of longitudinal vibration for neutral and first-speed and fifth-speed gear position (floor panel in location of driver feet, 1500 rpm)



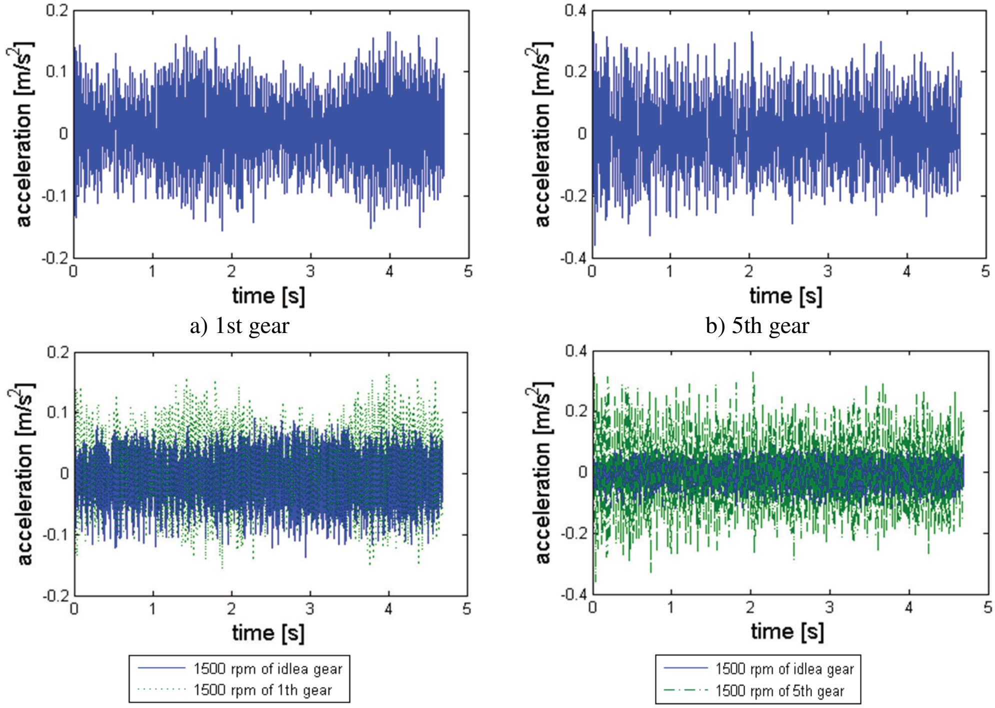
a) 1st gear

b) 5th gear

c) Idle gear vs 1st gear

d) Idle gear vs 5th gear

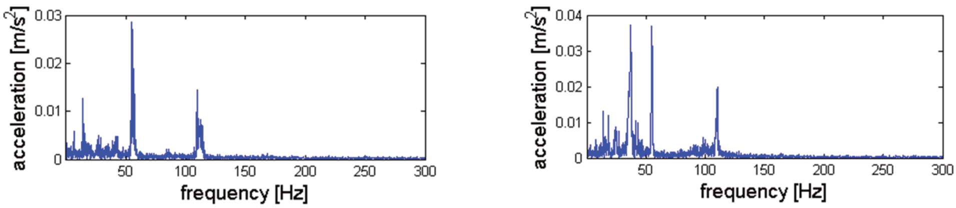
Fig. 14.12. The comparison of lateral vibration for neutral and first-speed and fifth-speed gear position (floor panel in location of driver feet, 1500 rpm)



a) 1st gear b) 5th gear

c) Idle gear vs 1st gear d) Idle gear vs 5th gear

Fig. 14.13. The comparison of vertical vibration for neutral and first-speed and fifth-speed gear position (floor panel in location of driver feet, 1500 rpm)

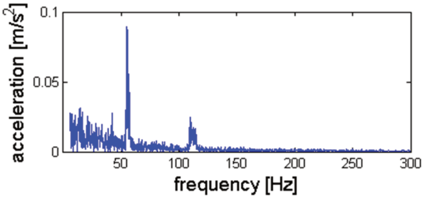


a) 1st gear b) 5th gear

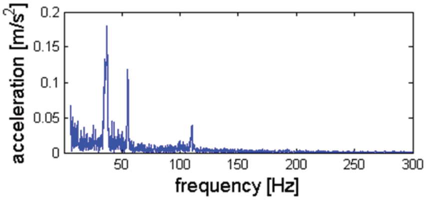
c) Idle gear vs. 1st gear d) Idle gear vs. 5th gear

e) Differential spectrum of 1st and idle gears f) Differential spectrum of 5th and idle gears

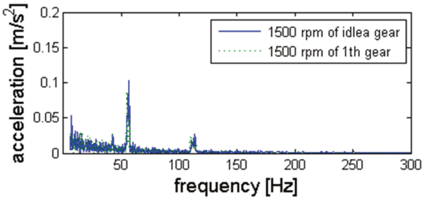
Fig. 14.14. The comparison of spectrums of longitudinal vibration for neutral and first-speed and fifth-speed gear position and differential spectrum of first and fifth-speed gears (floor panel in location of driver feet, 1500 rpm)



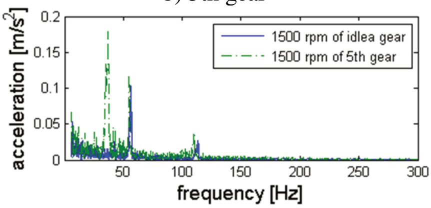
a) 1st gear



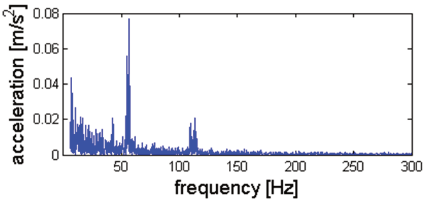
b) 5th gear



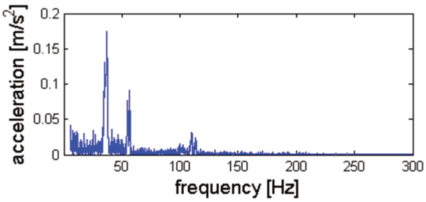
c) Idle gear vs. 1st gear



d) Idle gear vs. 5th gear

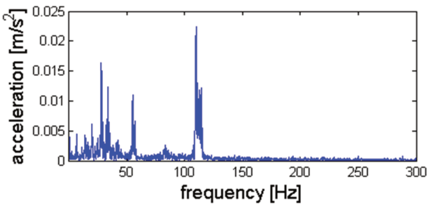


e) Differential spectrum of 1st and idle gears

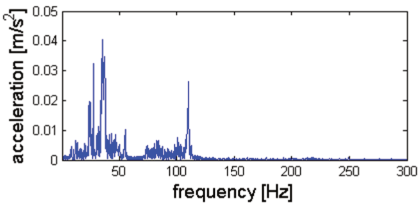


f) Differential spectrum of 5th and idle gears

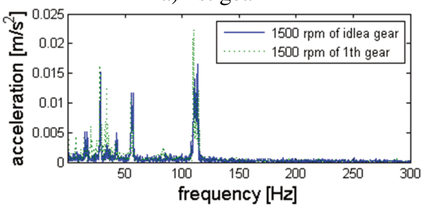
Fig. 14.15. The comparison of spectrums of lateral vibration for neutral and first-speed and fifth-speed gear position and differential spectrum of first and fifth-speed gears (floor panel in location of driver feet, 1500 rpm)



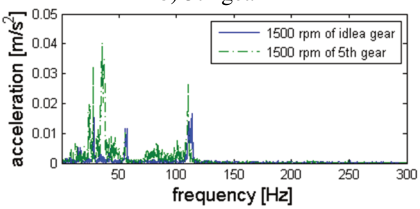
a) 1st gear



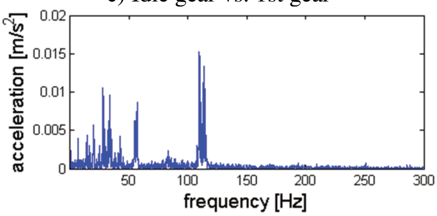
b) 5th gear



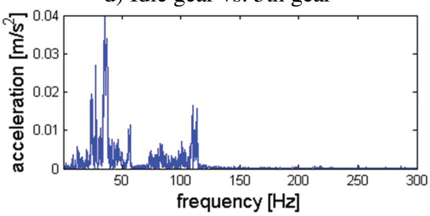
c) Idle gear vs. 1st gear



d) Idle gear vs. 5th gear

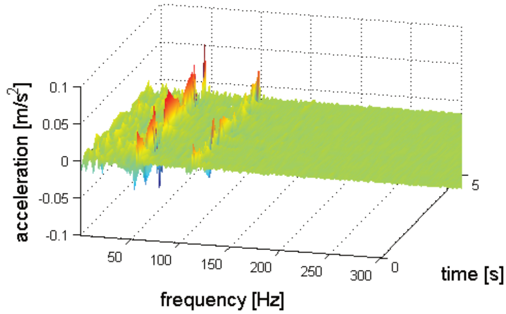


e) Differential spectrum of 1st and idle gears

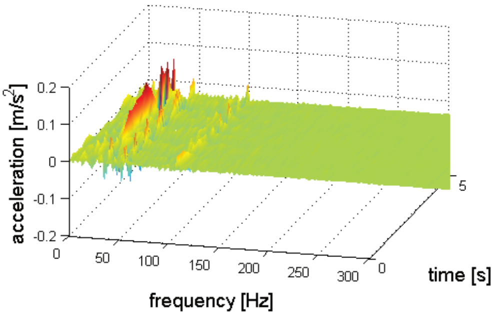


f) Differential spectrum of 5th and idle gears

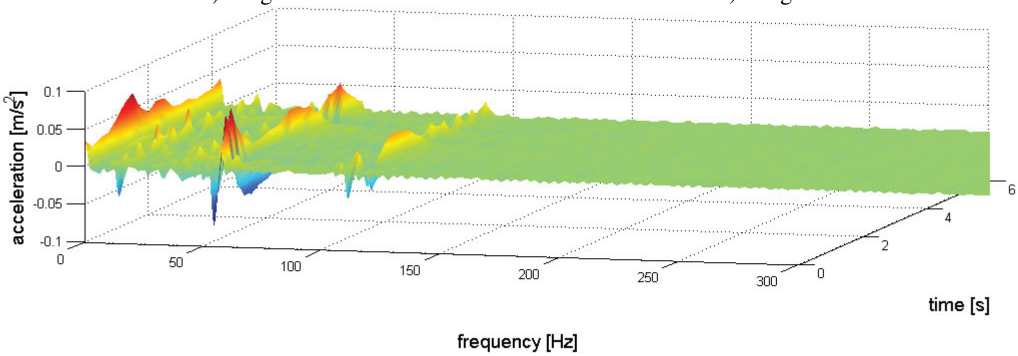
Fig. 14.16. The comparison of spectrums of vertical vibration for neutral and first-speed and fifth-speed gear position and differential spectrum of first and fifth-speed gears (floor panel in location of driver feet, 1500 rpm)



a) 1st gear

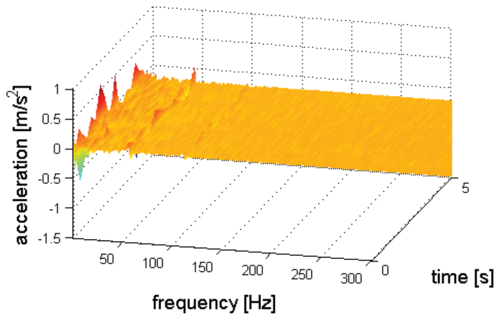


b) 5th gear

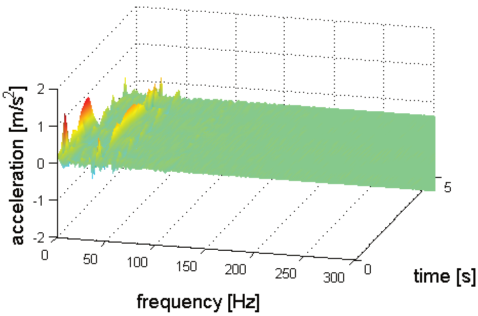


c) Idle gear

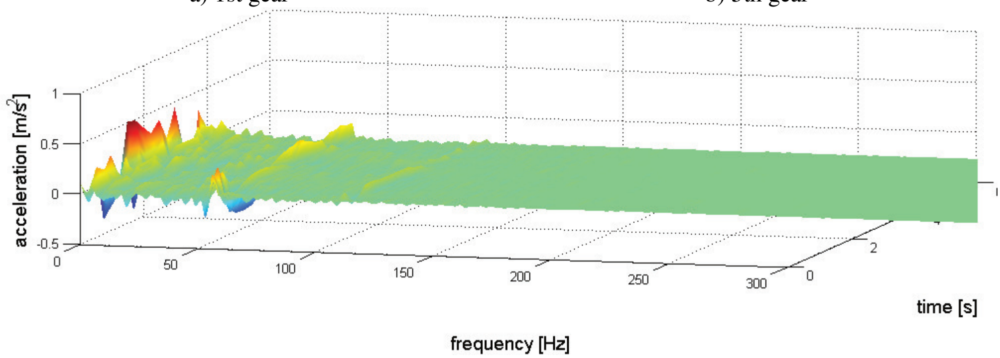
Fig. 14.17. The comparison of TFR of longitudinal vibration for neutral and first-speed and fifth-speed gear position (floor panel in location of driver feet, 1500 rpm)



a) 1st gear

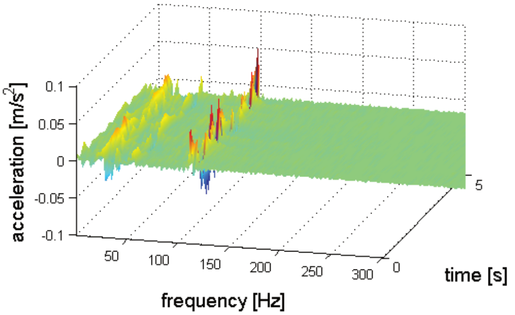


b) 5th gear

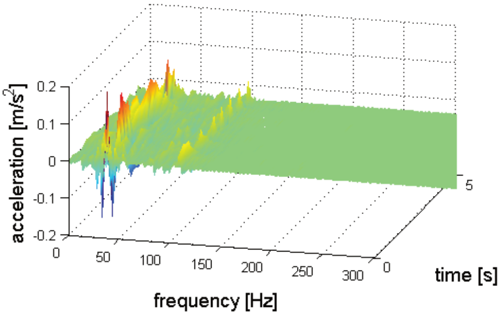


c) Idle gear

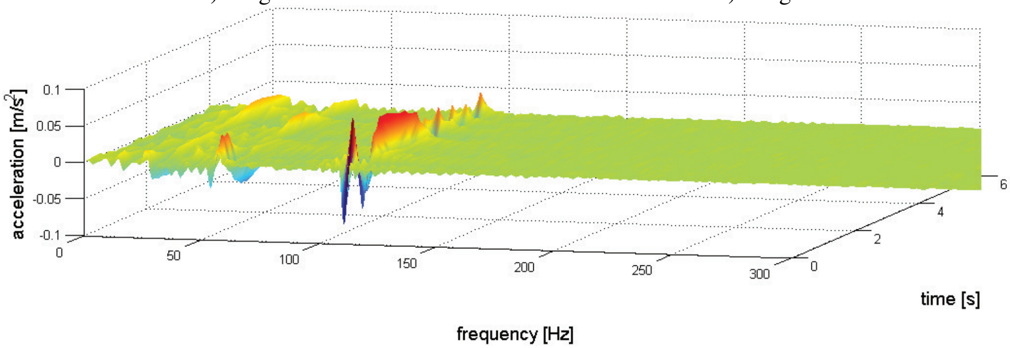
Fig. 14.18. The comparison of TFR of lateral vibration for neutral and first-speed and fifth-speed gear position (floor panel in location of driver feet, 1500 rpm)



a) 1st gear



b) 5th gear



c) Idle gear

Fig. 14.19. The comparison of TFR of vertical vibration for neutral and first-speed and fifth-speed gear position (floor panel in location of driver feet, 1500 rpm)

14.5. Discussion on influence of gear position in transmission gearbox on vibration

The directional distribution of vibration exposed on driver penetrate via feet for different gear position in gearbox, from first to fifth and reverse gear were presented in time, frequency and time-frequency domains. The successive gear ratio generate higher energy vibration with assumption that fifth and reverse gear vibration become a little lower. The values of estimators of energy of vibration considered in time, frequency and TFR representation of the signal were collected and compared to value reached for neutral gear, without gear ratio. All obtained results show an increase of energy of vibration compared to isolated engine vibration sources on the same rotational speed. The spectrums of the vibration allow to identify generation of lower to the main frequency components of the signal. Basing on the observation of TFR of vibration for different gear position some interesting phenomena can be found. Due to the increase of gear ratio the time distribution of the vibration of dominant frequency components become more constant.

For the purpose of identification of vibration components caused by the gearbox the result of vibration of neutral and first and fifth gears were summarized. The dynamic components can be identified by the comparison of spectrums and differential spectrum of neutral gear and running gear vibration. The results show that due to increase of gear ratio the correlation of spectrums of neutral and running gear become diminishes. The comparison of vibration spectrum of neutral and fifth gears shows many more different (low frequencies) components caused by the gear ratio. The differential spectrum allows to evaluate the influence of gear ratio on vibration dynamics. Due to the comfort and vibration exposure aspects it is important to analyse the energy, frequency but also the time of vibration components affecting on occupants. The TFR of the vibration collected as STFT of the vibration of gear ratio position and neutral idle gear position allow to observe simultaneous these exposure parameters.