12. Identification of vibration propagation paths from engine into the occupants

Vibration propagation research in vehicles should primarily pertain to their effects on occupants. Consequences of the human exposure to vibrations include various harmful changes occurring in the organism. They have a direct or indirect influence on comfort and safety. The scope and the procedure of handling them depend to a considerable extent on the location where they penetrate the organism. The vibration energy affecting the human organism originates in the direct penetration area exclusively, therefore, what matters for the vibration perception is the energy affecting a unit of surface area in a unit of time. Thus the identification of propagation paths is significant for isolating or preventing to the vibration transfer from sources.

As it was elaborated in previous chapter one of the major vibration source, especially in the traffic jam, is engine. Fig. 12.1 illustrates propagation of the engine vibration to the driver body.

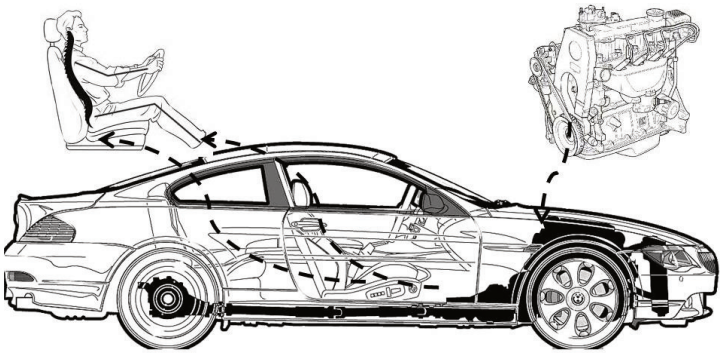


Fig. 12.1. Engine vibration transfer into human organism

12.1. Research on vibration propagation paths from engine to car body in locations of penetrate into human body

Active experiments were undertaken featuring measurements of vibration accelerations in a three directions in numerous selected points to analyse propagation of vibration generated by engine to human body via feet and lumbar spine. Vibration in three orthogonal axes (X – longitudinal, Y – lateral, Z – vertical) was recorded. The purpose of the research was to analyses the car body vibration generated from motor engine. The vehicles tested during research were passenger cars with most common used four cylinder, four-stroke engine. The identification of those kind of engine as vibration source was described in previous chapter. The experiments were conducted on the car vehicle which was placed on the special test racks. It allows to eliminate the road roughens impact on the suspension and in result to car body.

The vibration signals were measured in 10 points in vehicle (Fig. 12.2). It enables identifying many combinations of vibration propagation paths. The chapter presents result of vibration grouped in 4 dominants propagation paths:

I. Vibration source – engine, dash panel, floor panel under the driver's feet, driver's seat (Fig. 12.2 points 1-2-3-4);

II. Vibration source – engine, floor panel under the rear left passenger's feet, left rear seat, right rear seat (Fig. 12.2 points 1-6-7-5);

III. Vibration source – engine, floor panel under the driver's feet, driver's seat, right front (front passenger) seat (Fig. 12.1 points 1-3-4-8);

IV. Vibration source – engine, floor panel under the front passenger's feet, right front seat, floor panel under the rear right passenger's feet (Fig. 12.2 points 1-9-8-10).

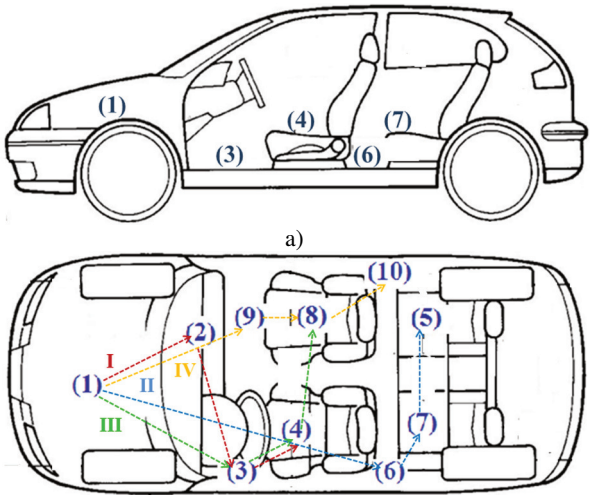
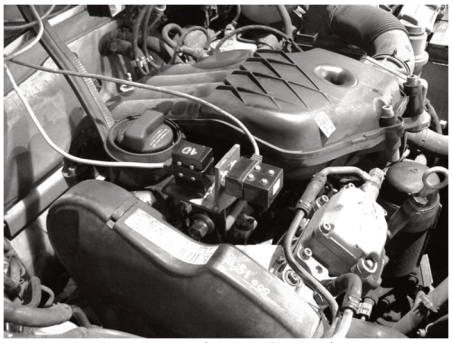


Fig. 12.2. Locations of vibration measurement points in vehicle structure



a) Propagation path: engine

b) Propagation path: floor panel under driver feet

c) Propagation path: dash panel

d) Propagation path: river seat

Fig. 12.3. Examples of vibration sensors mounting

The main reasons of choosing these 4 propagation paths were possibilities of structural waves

propagation from engine via frame and car body into human body (feet and lumbar spine). It enables to analyse the way of vibration transfer from the source to occupants. Vehicle vibrations are transmitted to the occupant's lumbar spine and chest by the seat. The floor panel transmit additional vibrations to the feet. These vibrations cause a level of discomfort for driver and passengers. Examples of vibration sensors mounting for propagation path: engine, dash panel, floor panel under driver's feet and driver's seat are presented in Fig. 12.3.

The established scope of research enables to observe changes of the vibration for chosen points on the vibration propagation paths from engine. The three orthogonal axes were analysed separately. Thus the comparison of the acceleration of vibration signals allows determine which directions of the vibration propagation is parent.

12.2. Propagation and structure of vibration transferred from engine to car body

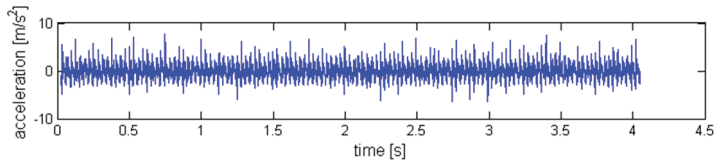
For the purpose of identifying of vibration propagation paths from engine to car body in terms of comfort and safety the transfer of the vibration to the locations of penetration into occupants have to be consider. Vibrations propagate into the human organism through vehicle seats via the pelvis, the back and lateral parts of the body as well as through the vehicle floor panel via feet.

The vibration signals were grouped in 4 dominants propagation paths included locations where they penetrate the organism. Thus the vibration transfer from engine to the floor panel and seats have been analysed. The complex analysis of vibrations due to the human exposure require observation of distribution on time, frequency and time-frequency representation.

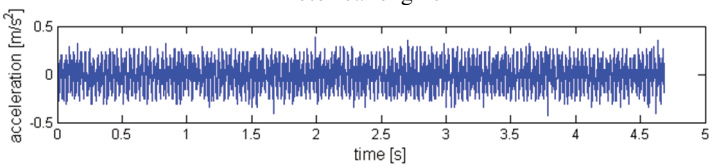
12.2.1. Vibration propagation into driver

Observation of time distribution of vibration transferred from engine, via dash panel to the driver by the feet or seat enables evaluation of dissipation of energy. The Fourier transformation shows influence of propagation paths on dynamics of vibration (Figs. 12.4-12.6). The analysis of the vibration structure, as TFR, permit to identify the periods of temporary excited vibration. The collection of vibration distribution in the following measurement points on propagation path are presented in Figs. 12.7-12.9.

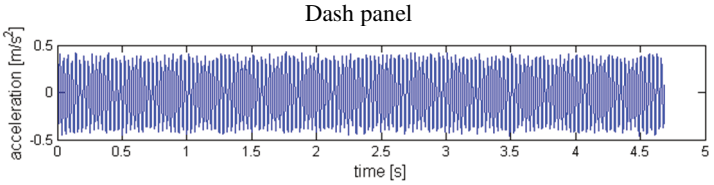
The lateral vibration measured on the floor panel under the driver's feet have constant low-frequency component which can be correspond to the rocking movement. Thus the energy of the frequency dominant peak is lower. It can be result of measurement process. Apart this the decrease of the vibration energy for following measurement points is significant. It can be assumed that lateral and vertical vibration transferred from engine to the driver are ca. one hundred times lower.



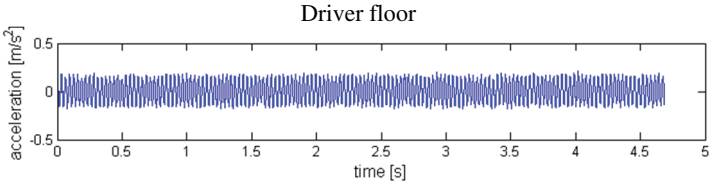
Motor-car engine



Dash panel

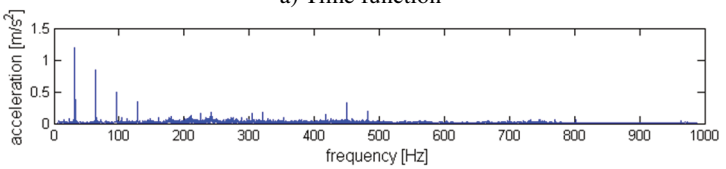


Driver floor

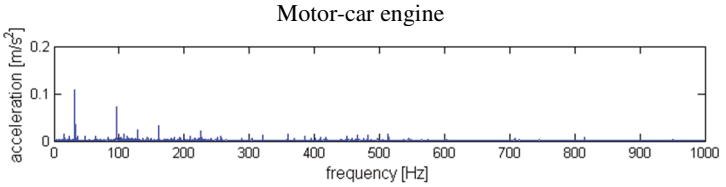


Driver seat

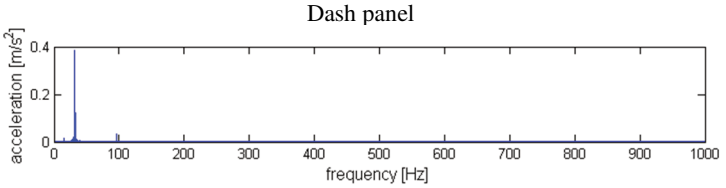
a) Time function



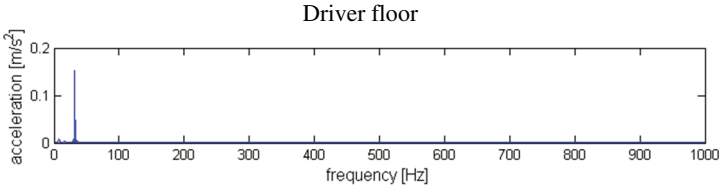
Motor-car engine



Dash panel



Driver floor



Driver seat

b) Frequency function

Fig. 12.4. Propagation of the vibration, path No. I., *X* axis – longitudinal, 750 rpm

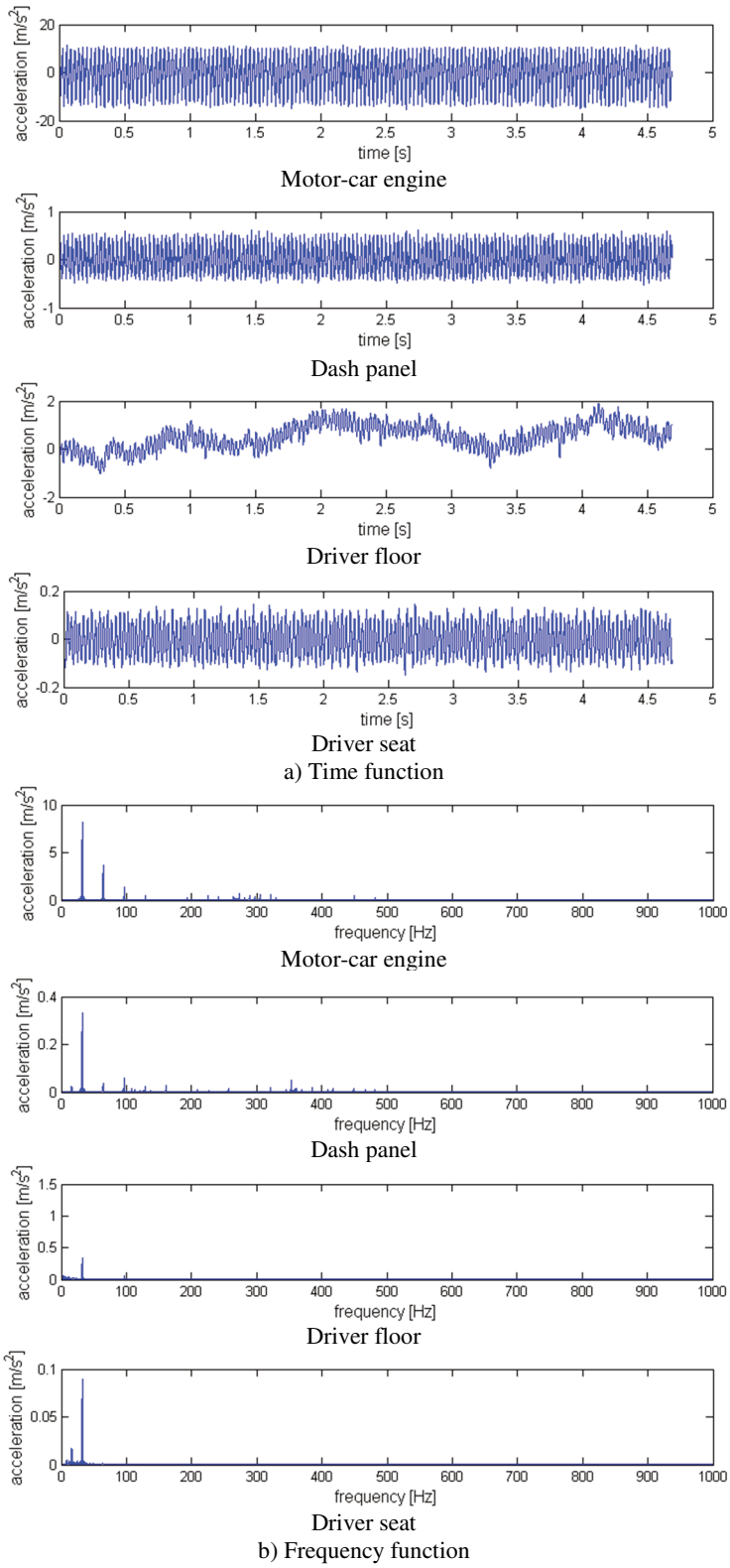


Fig. 12.5. Propagation of the vibration, path No. I., *Y* axis – lateral, 750 rpm

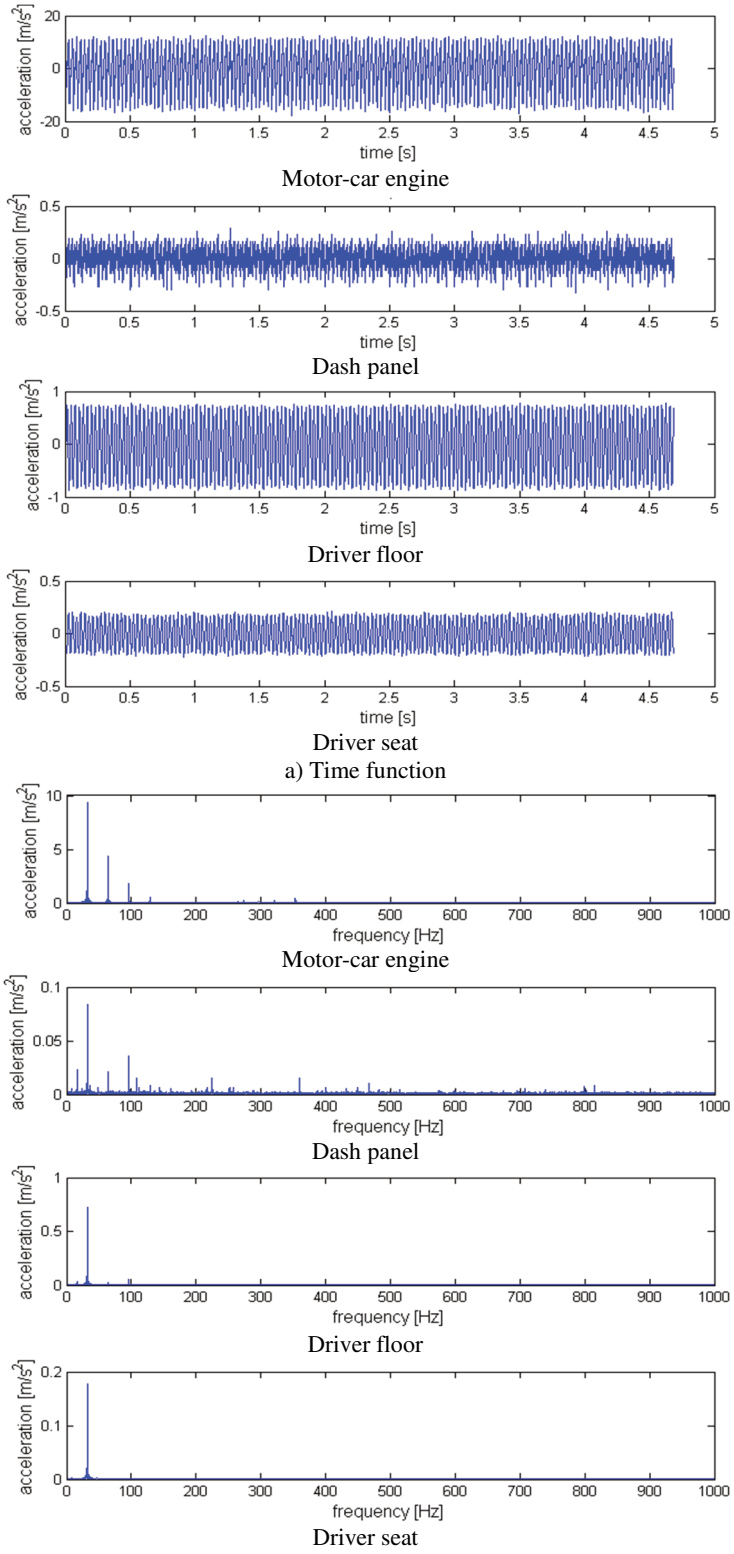


Fig. 12.6. Propagation of the vibration, path No. I., *Z* axis – vertical, 750 rpm

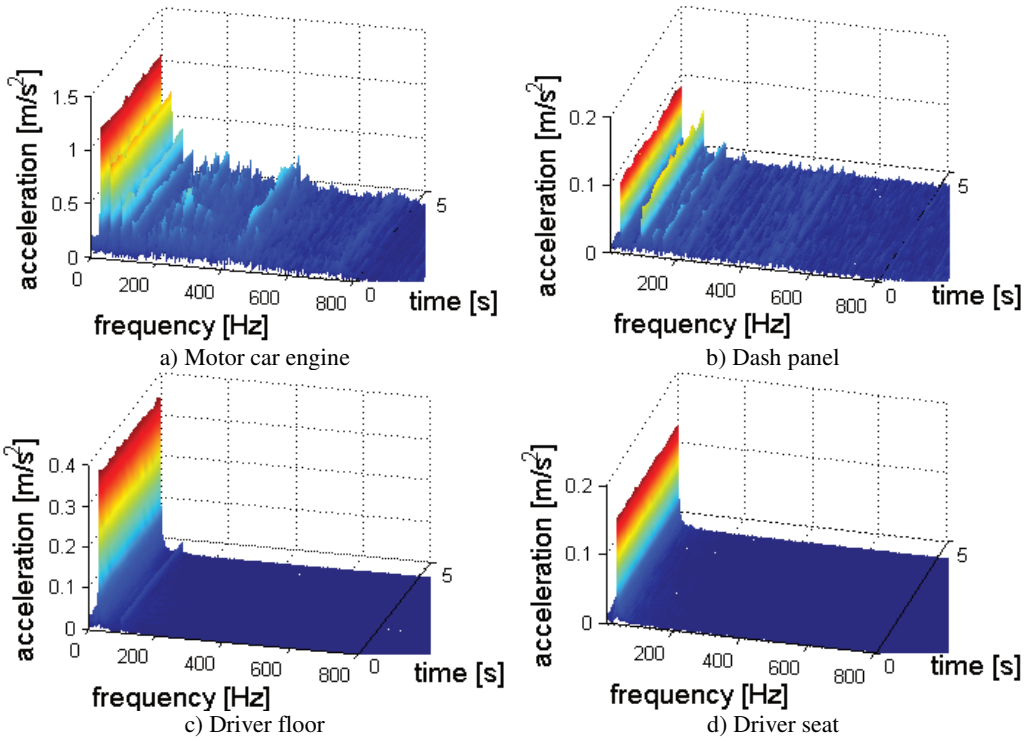


Fig. 12.7. Changes of the structure of vibration during propagation, path No. I., *X* axis – longitudinal

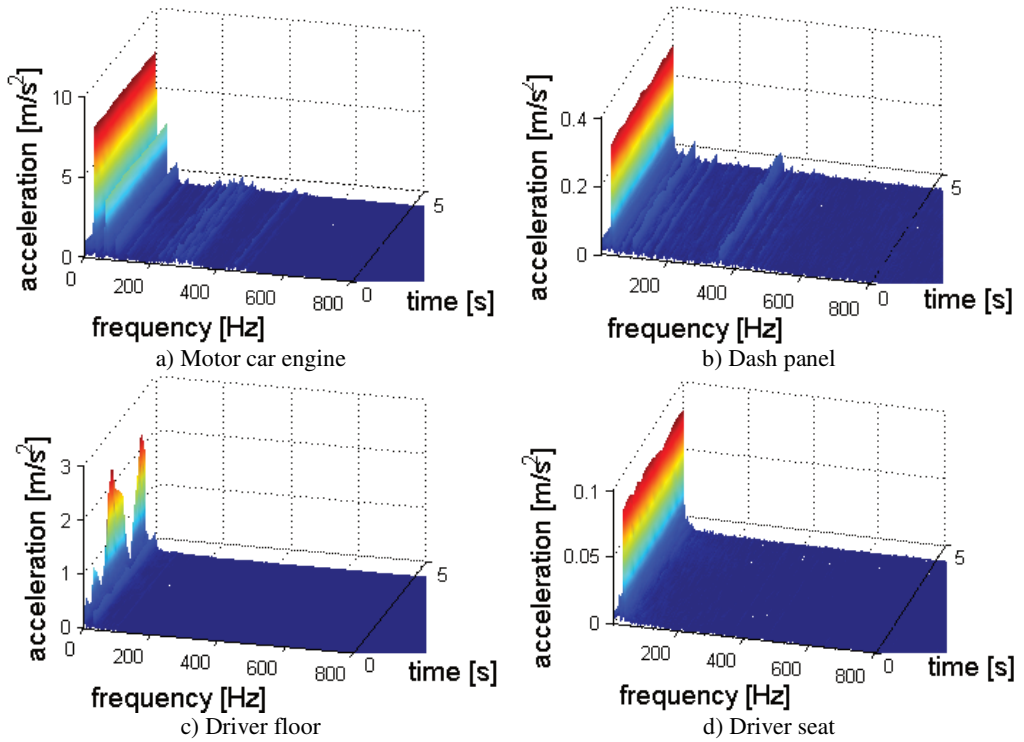


Fig. 12.8. Changes of the structure of vibration during propagation, path No. I., *Y* axis – lateral

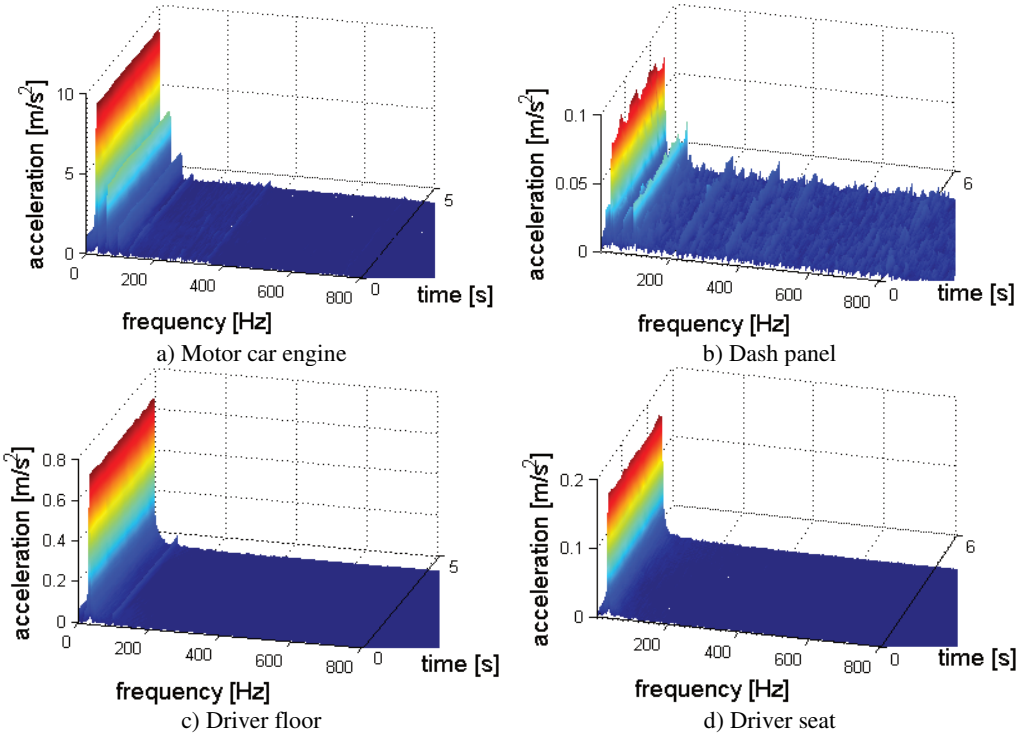


Fig. 12.9. Changes of the structure of vibration during propagation, path No. I., *Z* axis – vertical

12.2.2. Vibration propagation into rear passengers

The propagation of the vibration generated by the engine has to be considered for all occupants. The scope of the research included observation of the vibration effected on passengers sitting on the rear seats. The main propagation path consist the location points on floor panel under left rear passenger's feet, left rear passenger's seat and right rear passenger's seat. These are location where whole body vibration penetrate into the human organism.

The collection of vibration distribution in the following measurement points on propagation path are shown in Figs. 12.10-12.12.

The analysis of structure of longitudinal and lateral vibration enable evaluation of exposure to whole body vibration in horizontal directions (Figs. 12.13-12.15). The dissipation of the vibration energy on propagation path is large between source (engine) and floor panel and seats. It shows the level of isolation or absorption of engine mounting system and suspension of the seats. The energy of the vibration affecting rear passengers in horizontal surface is similar.

The structure of vertical vibration affecting rear passengers via the floor and seats are similar as well, i.e. amplitude and frequency domains. For all result the vibration time distribution of dominant frequency band determined from the signals registered on floor panel (under the left rear passenger's feet) aren't constant.

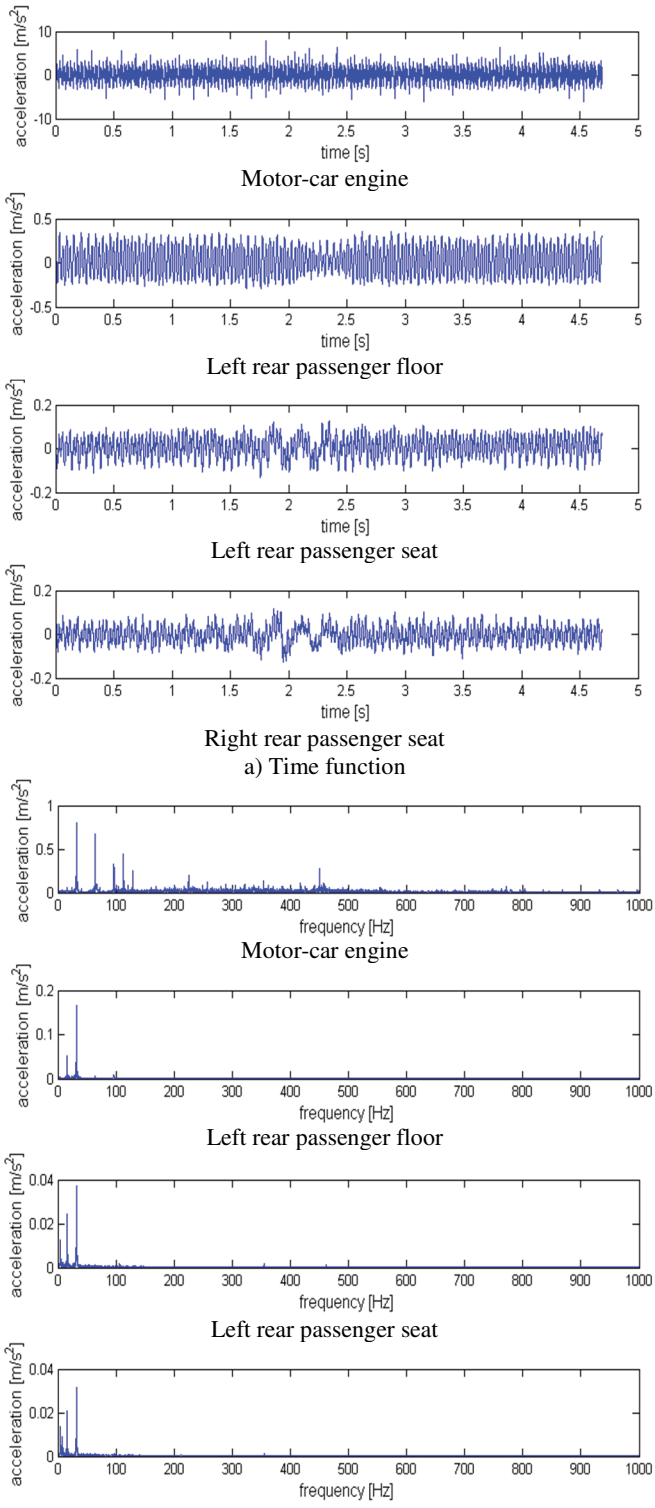
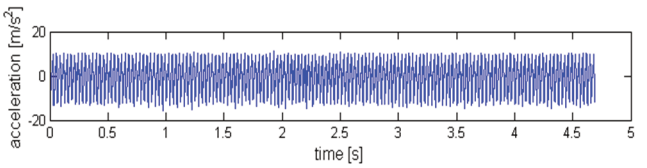
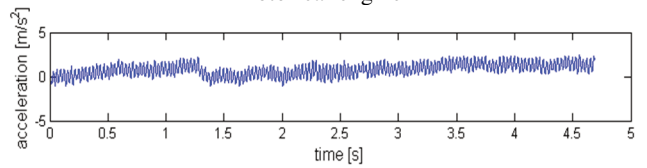


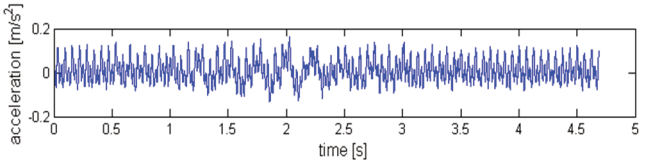
Fig. 12.10. Propagation of the vibration, path No. II., *X* axis – longitudinal, 750 rpm



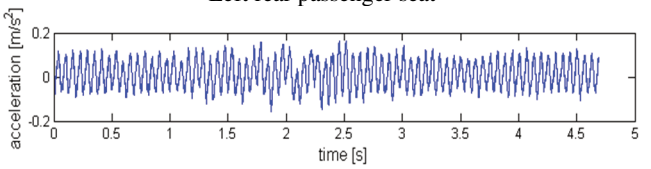
Motor-car engine



Left rear passenger floor

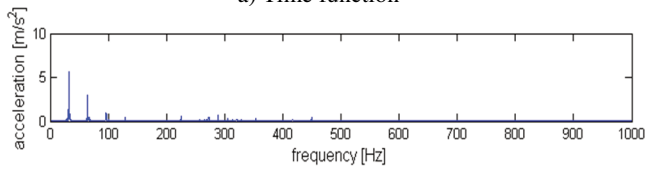


Left rear passenger seat

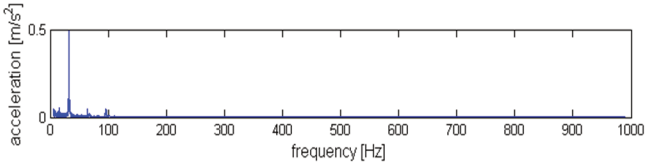


Right rear passenger seat

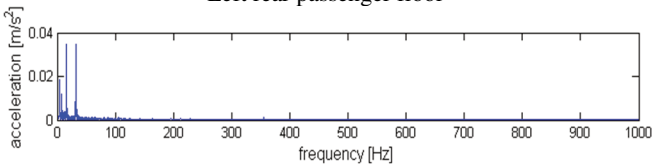
a) Time function



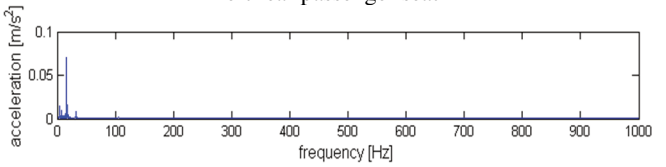
Motor-car engine



Left rear passenger floor



Left rear passenger seat



Right rear passenger seat

b) Frequency function

Fig. 12.11. Propagation of the vibration, path No. II., *Y* axis – lateral

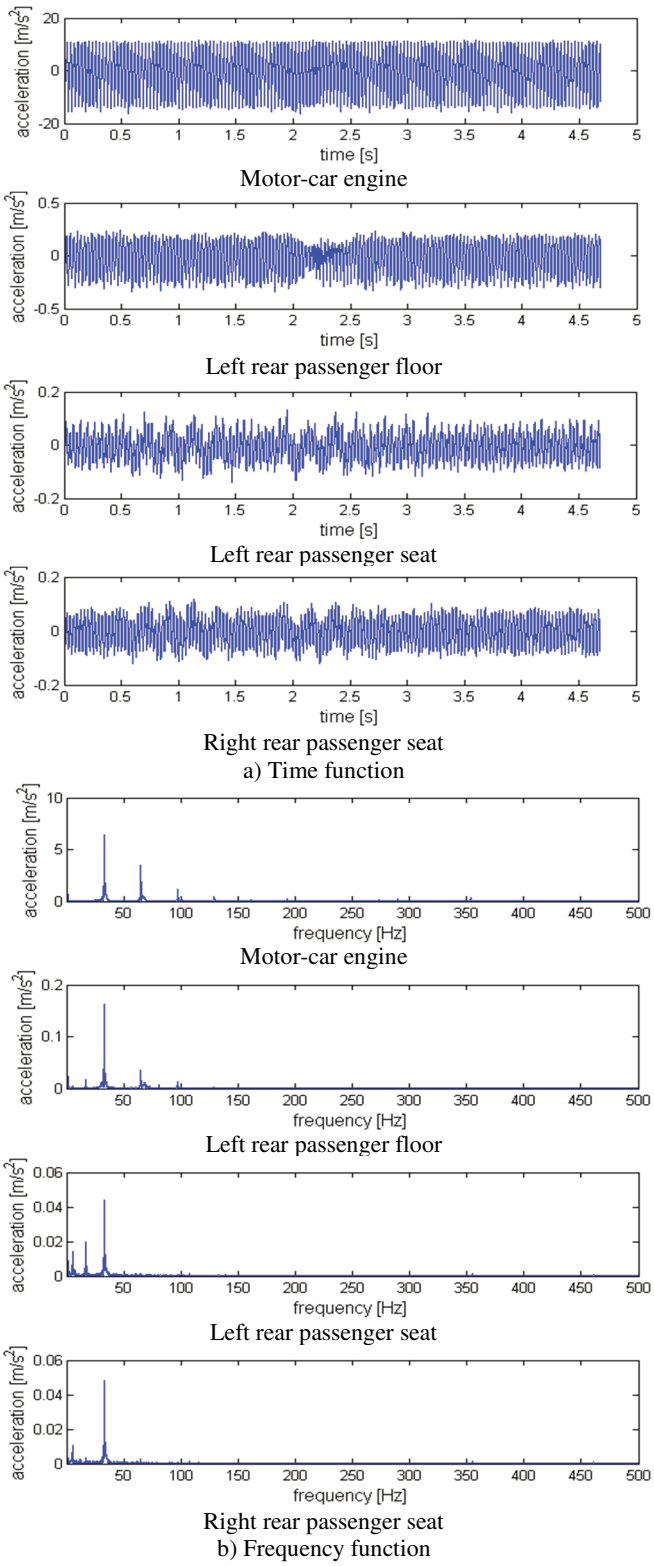
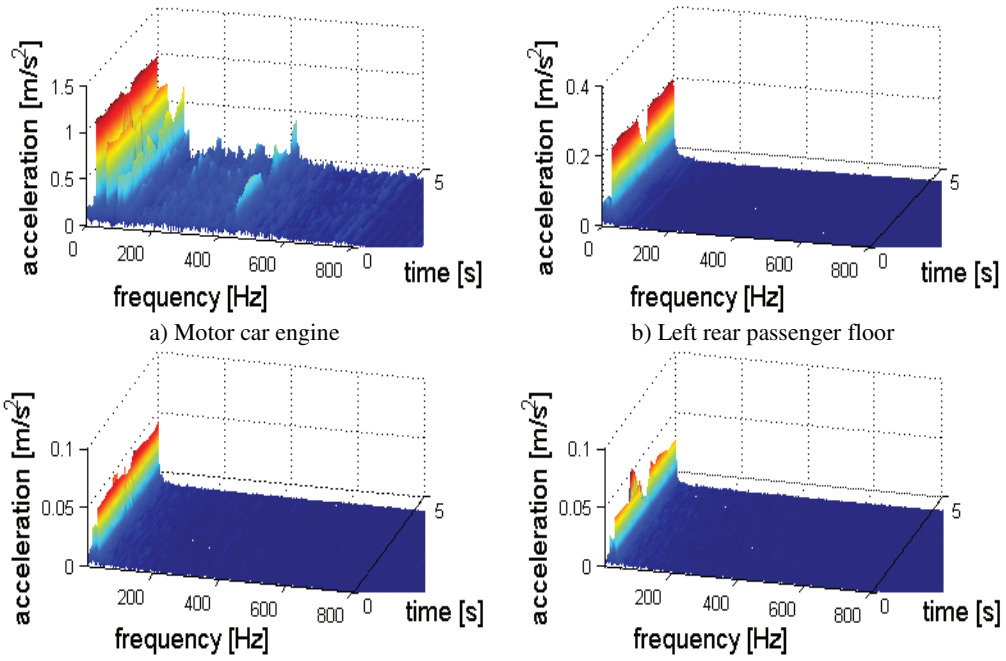


Fig. 12.12. Propagation of the vibration, path No. II., *Z* axis –vertical, 750 rpm



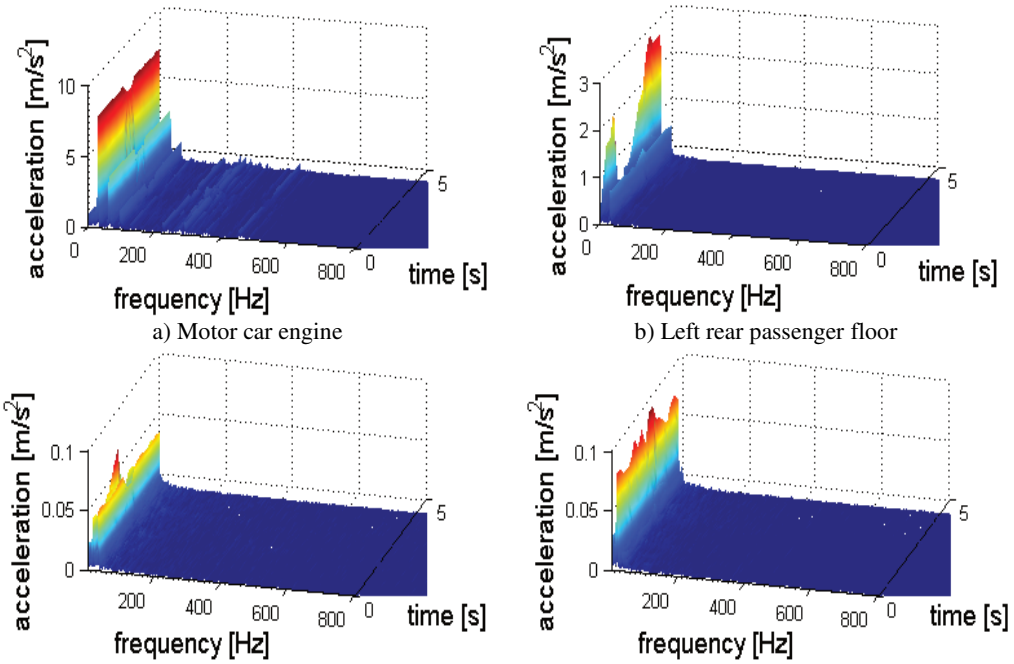
a) Motor car engine

b) Left rear passenger floor

c) Left rear passenger seat

d) Right rear passenger seat

Fig. 12.13. Changes of the structure of vibration during propagation, path No. II., *X* axis – longitudinal



a) Motor car engine

b) Left rear passenger floor

c) Left rear passenger seat

d) Right rear passenger seat

Fig. 12.14. Changes of the structure of vibration during propagation, path No. II., *Y* axis – lateral

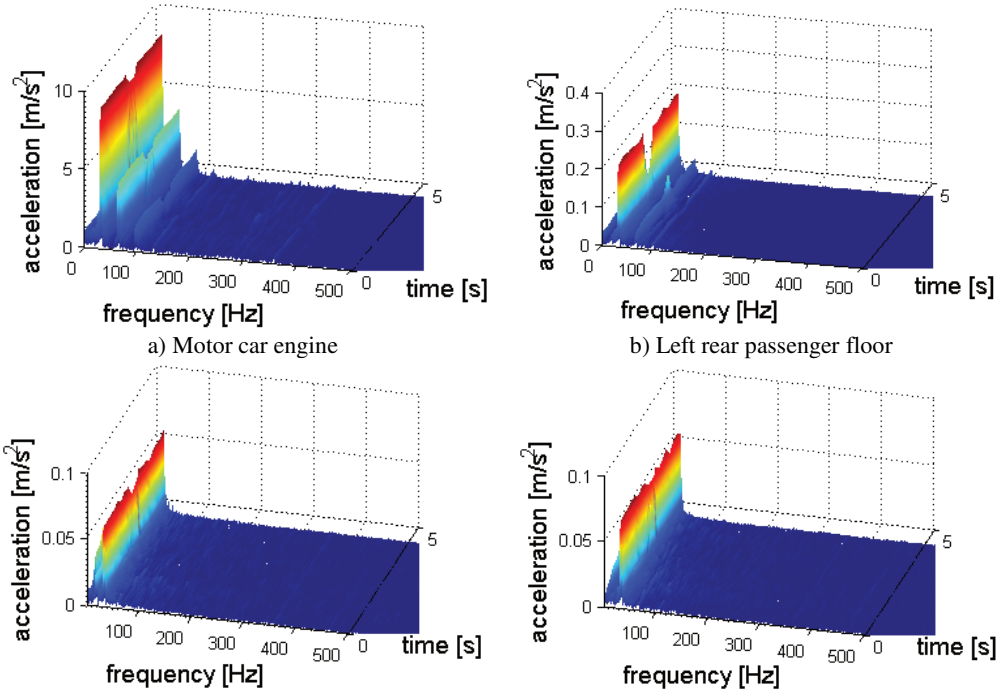


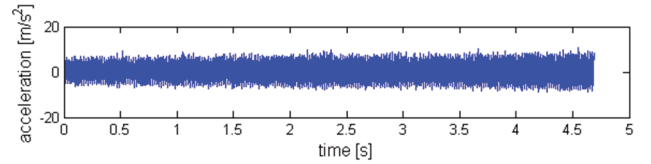
Fig. 12.15. Changes of the structure of vibration during propagation, path No. II., *Z* axis –vertical

12.2.3. Vibration propagation into front occupants

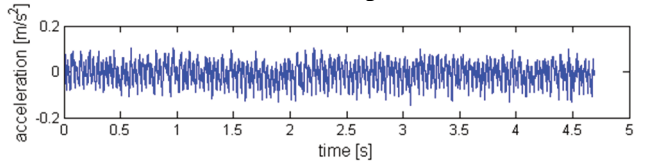
For the purpose of comparison of vibration exposure to all occupants of vehicle the propagation of the vibration generated by the engine to the front occupants were analysed. The front occupants mean driver and front passenger.

The collection of vibration distribution in the following measurement points on propagation path are shown in Figs. 12.16-12.21.

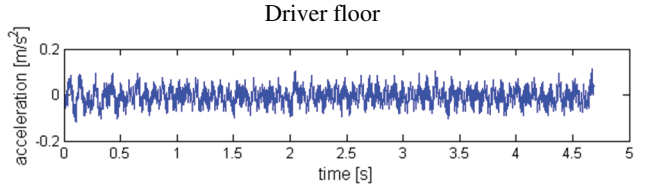
Basing on the analysis of vertical vibration registered on front occupants seats it can be assumed that suspension systems of front seats have good vibroisolation properties. Apart of minimize of the amplitudes in dominant frequencies its filters the higher frequencies similar to lowpass filters.



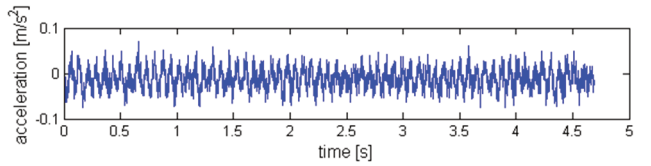
Motor-car engine



Driver floor

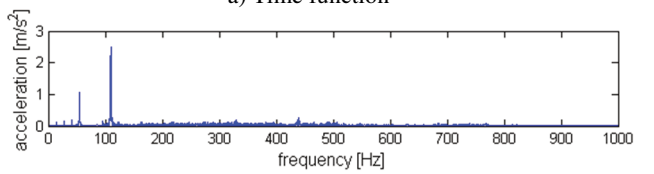


Driver seat

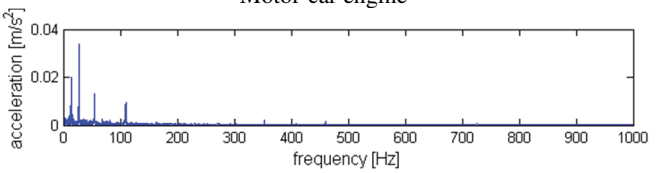


Front passenger seat

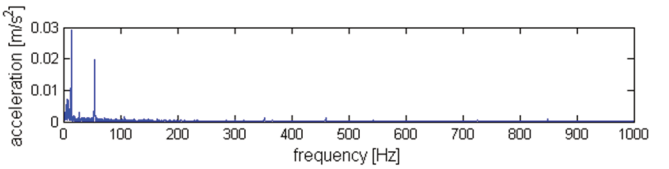
a) Time function



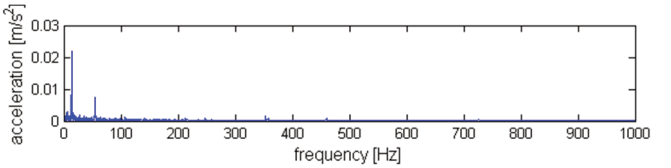
Motor-car engine



Driver floor



Driver seat



Front passenger seat

b) Frequency function

Fig. 12.16. Propagation of the vibration, path No. III, *X* axis – longitudinal, 750 rpm

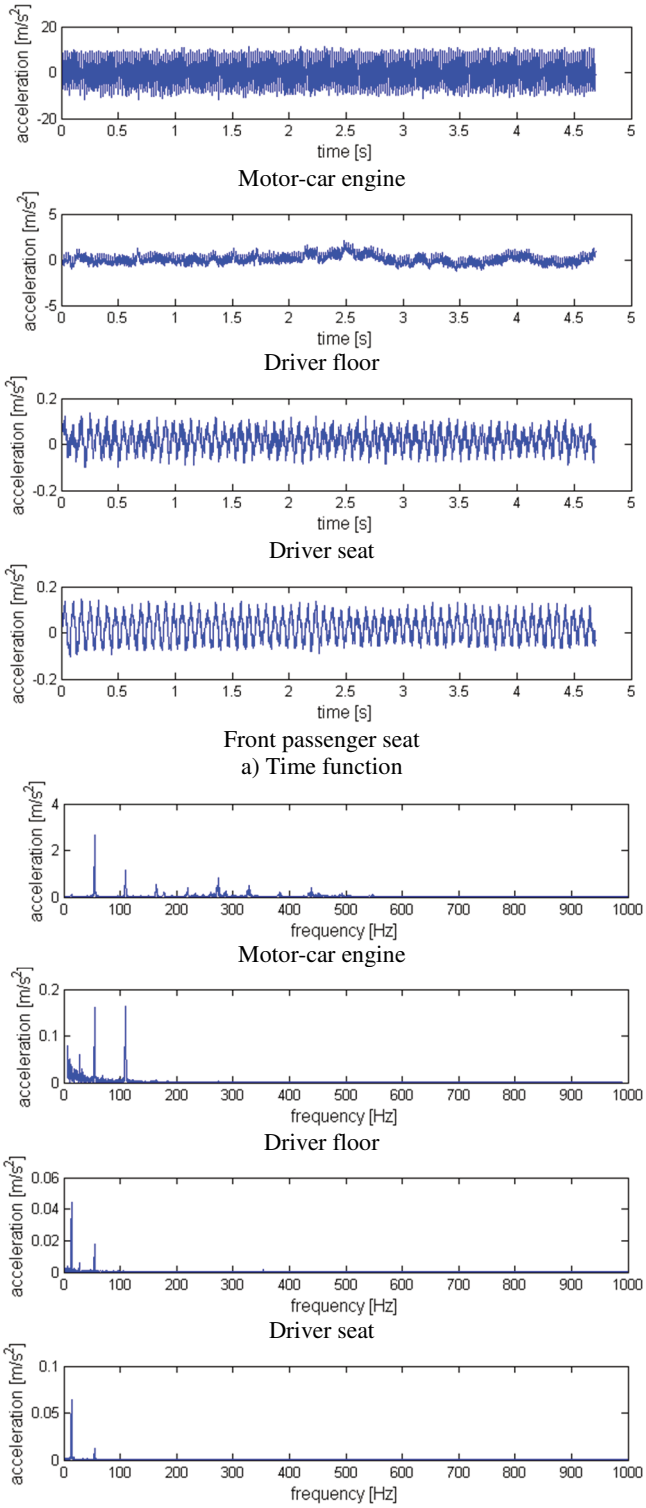
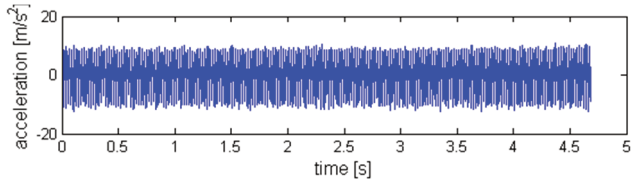
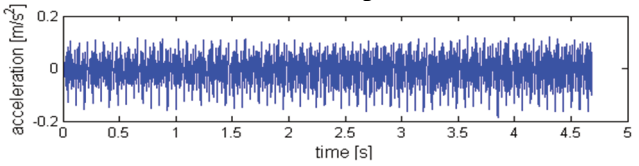


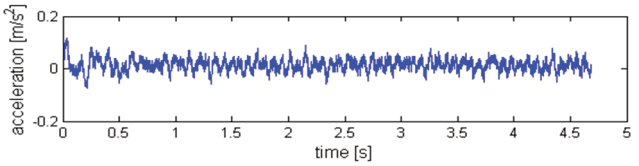
Fig. 12.17. Propagation of the vibration, path No. III, *Y* axis – lateral, 750 rpm



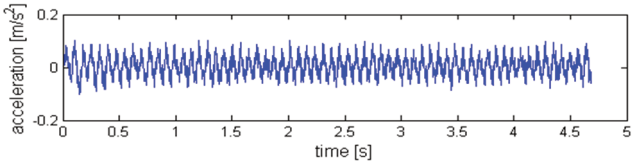
Motor-car engine



Driver floor

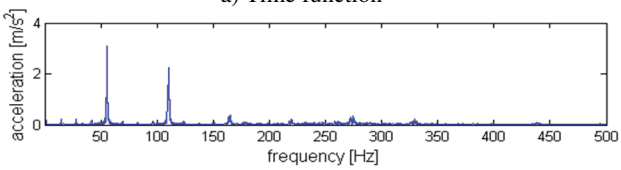


Driver seat

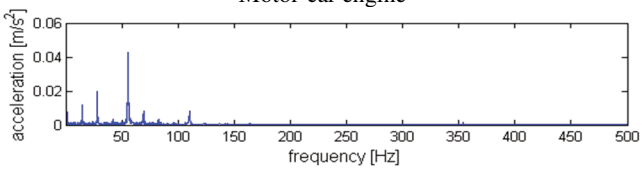


Front passenger seat

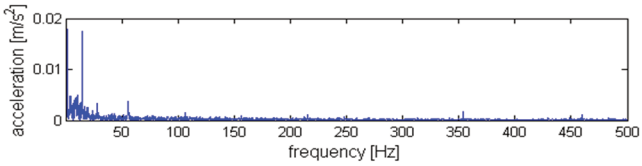
a) Time function



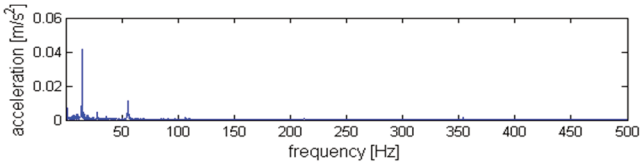
Motor-car engine



Driver floor



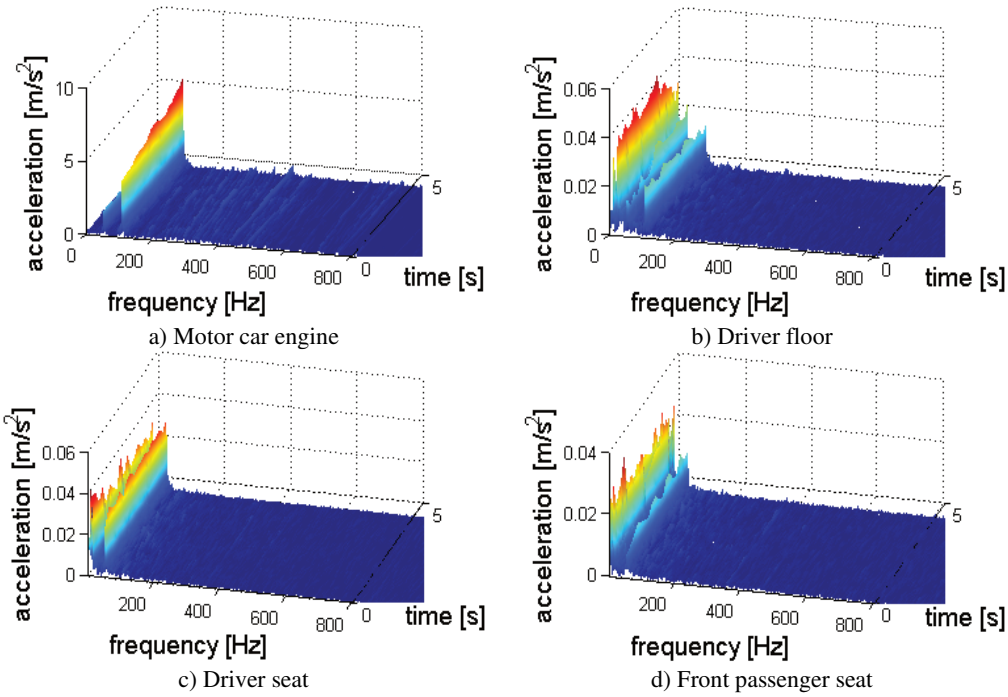
Driver seat



Front passenger seat

b) Frequency function

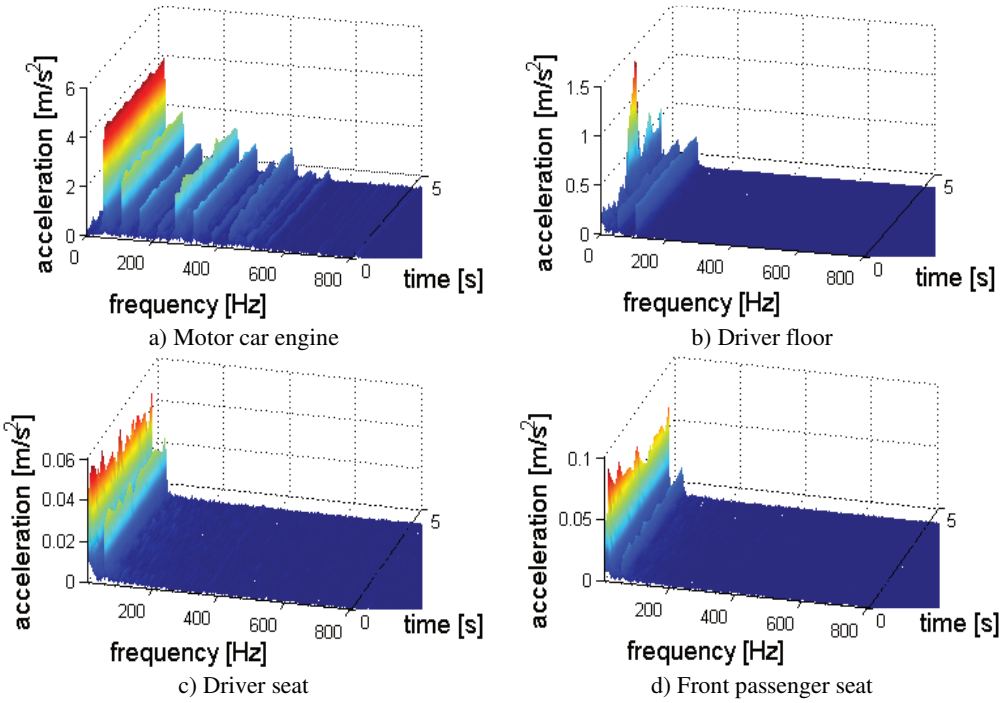
Fig. 12.18. Propagation of the vibration, path No. III, *Z* axis – vertical



a) Motor car engine b) Driver floor

c) Driver seat d) Front passenger seat

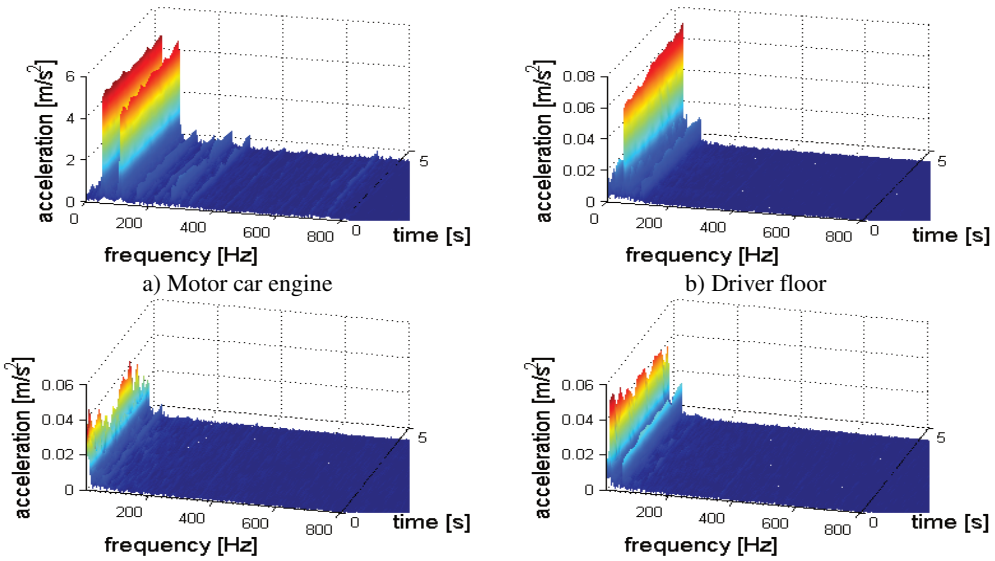
Fig. 12.19. Changes of the structure of vibration during propagation, path No. III, *X* axis – longitudinal



a) Motor car engine b) Driver floor

c) Driver seat d) Front passenger seat

Fig. 12.20. Changes of the structure of vibration during propagation, path No. III, *Y* axis – lateral



a) Motor car engine

b) Driver floor

c) Driver seat

d) Front passenger seat

Fig. 12.21. Changes of the structure of vibration during propagation, path No. III, *Z* axis – vertical

12.2.4. Vibration propagation into front passenger

For the purpose of identifying of vibration propagation paths into front passenger the engine vibration dynamic response of the vehicle structure on the right side was registered. The signals were measured in location of front passenger feet and seat and floor panel under rear right passenger feet.

The collection of vibration distribution in the following measurement points on propagation path are shown in Figs. 12.22-12.27.

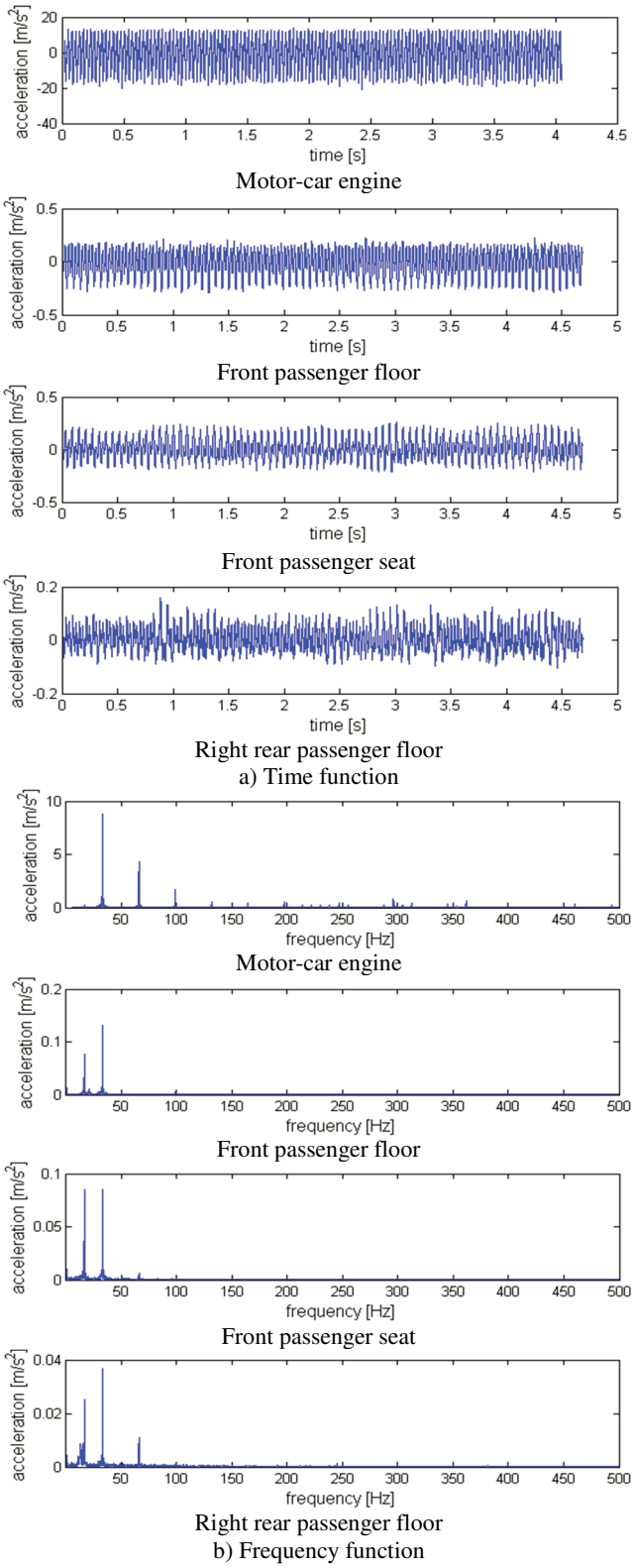
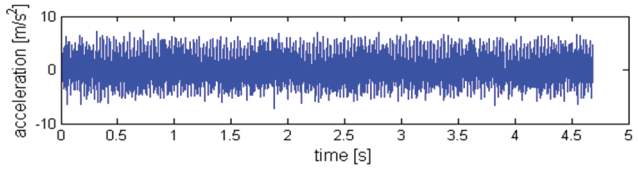
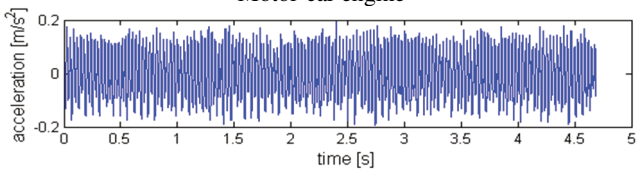


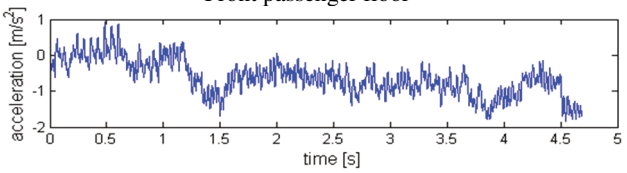
Fig. 12.22. Propagation of the vibration, path No. IV, *X* axis – longitudinal, 750 rpm



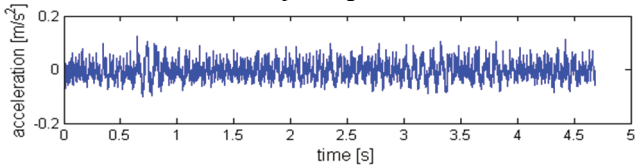
Motor-car engine



Front passenger floor

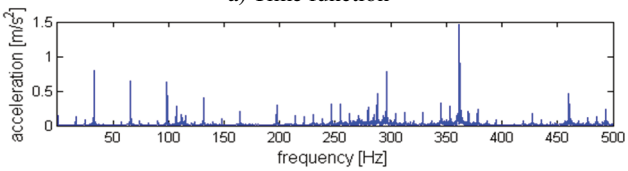


Front passenger seat

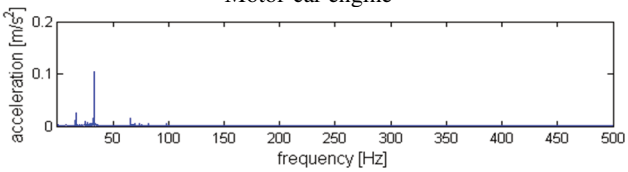


Right rear passenger floor

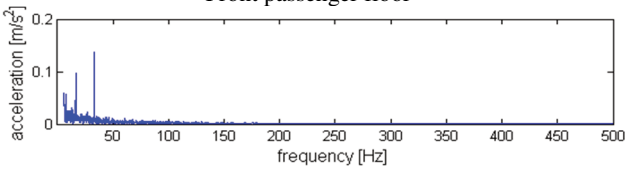
a) Time function



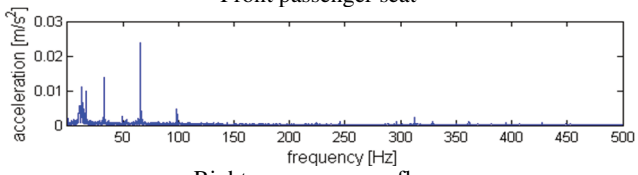
Motor-car engine



Front passenger floor



Front passenger seat



Right rear passenger floor

b) Frequency function

Fig. 12.23. Propagation of the vibration, path No. IV, *Y* axis – lateral, 750 rpm

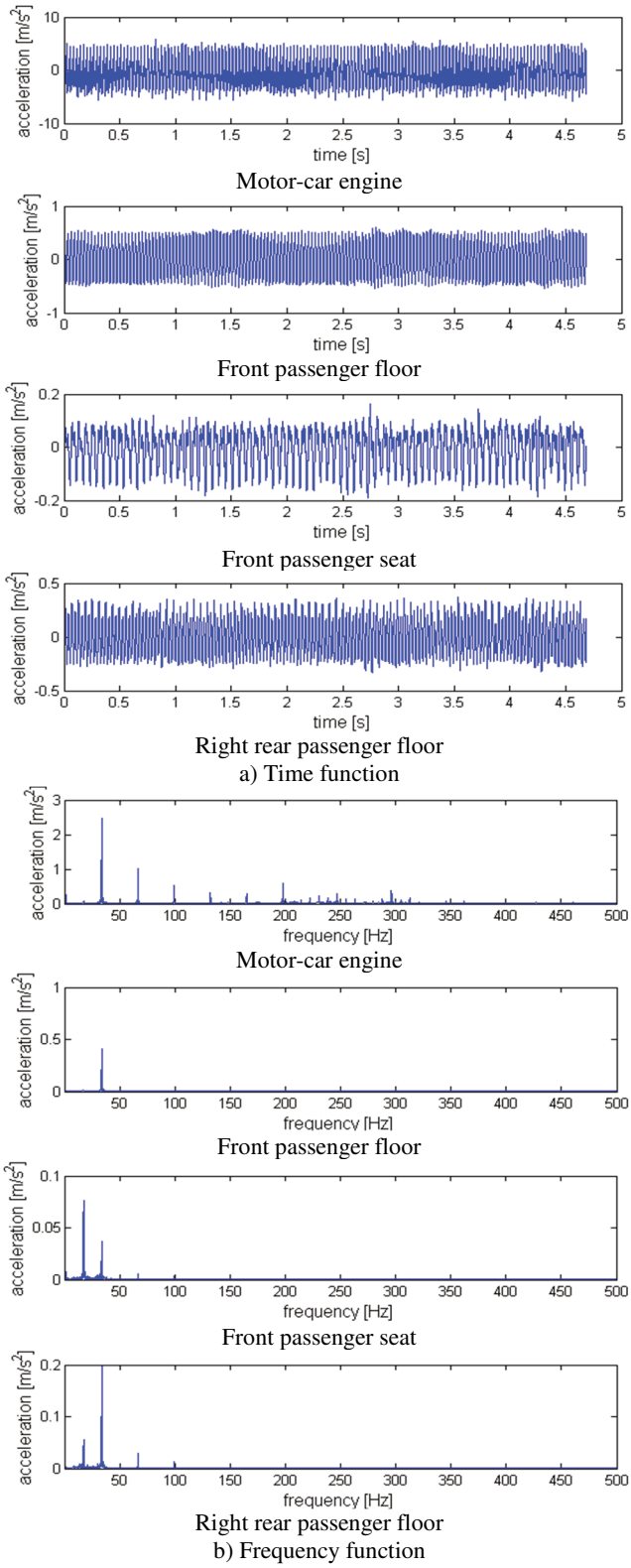
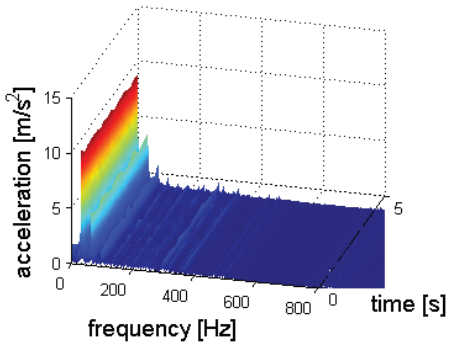
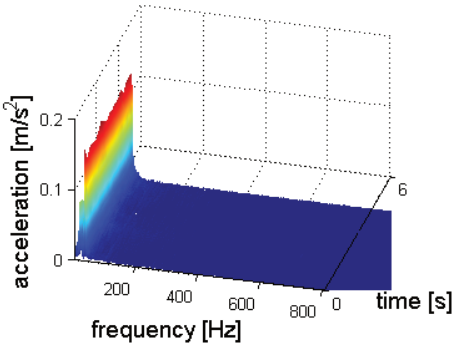


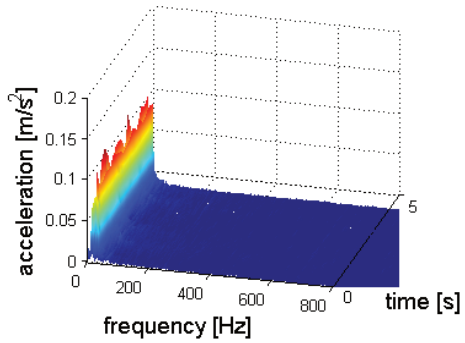
Fig. 12.24. Propagation of the vibration, path No. III, *Z* axis –vertical, 750 rpm



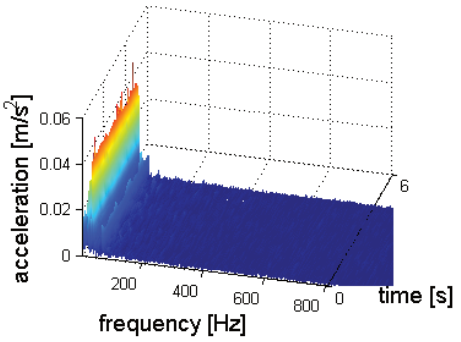
a) Motor car engine



b) Front passenger floor

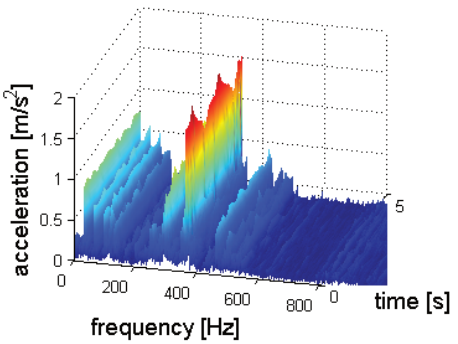


c) Front passenger seat

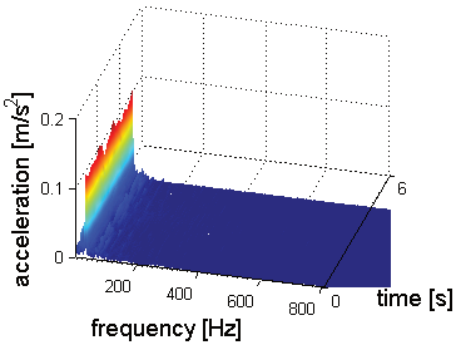


d) Right rear passenger floor

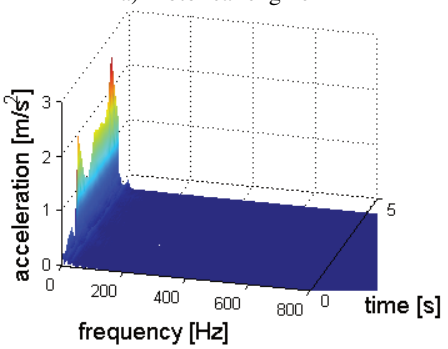
Fig. 12.25. Changes of the structure of vibration during propagation, path No. IV, *X* axis – longitudinal



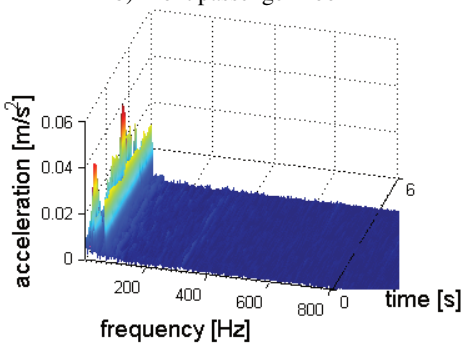
a) Motor car engine



b) Front passenger floor



c) Front passenger seat



d) Right rear passenger floor

Fig. 12.26. Changes of the structure of vibration during propagation, path No. III, *Y* axis – lateral

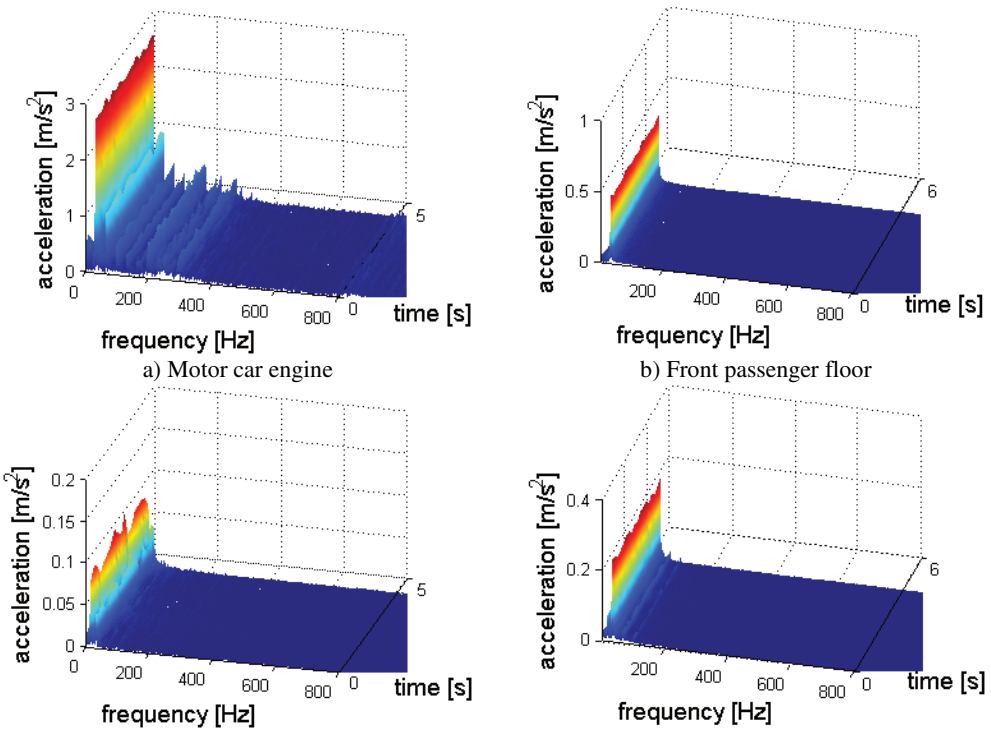


Fig. 12.27. Changes of the structure of vibration during propagation, path No. III, *Z* axis – vertical

Propagation of the horizontal vibration shows relation between vibration and distance from the source. Thus the vibration of the floor panel in location of rear right passenger feet are much smaller than the vibration of the floor panel closer to the engine source in location of front passenger feet. The vibration registered on the front passenger seat are higher than long distance vibration of the floor panel. The vertical vibration are higher on the floor panel than on the seat. It can be assumed that suspension of the seat has better properties for absorbing the vertical vibration.

The results of the research enable analyzing the vibration propagation from engine to human body. The structures and directional distribution of the vibrations have been registered in the location where vibrations penetrate into the human organism. The vibration of floor panel and seats have got much more less higher frequencies components. Thus it can be assumed that vibration during propagation into the vehicle construction and equipment (seats) dissipate in the first step energy correlated to the higher than main harmonic frequencies. Also the whole-body vibration in location of penetration into the human organism transfer part of the vibration into the lower frequencies due to the decrease of the total energy volume. The values of the vibration of the motor engine are much higher than floor panel vibration. This proves good vibration isolation in a vehicle cab. Domination of lower frequencies in the signal registered on vehicle floor panel can be observed.

For the purpose of comparison of the vibration propagation paths into the occupants of the passenger car some estimators of the energy dissipation can be very helpful. Propositions of the vibration dissipation estimators for time and frequency domains are presented in Chapter 17.