6. The influence of the technical condition of suspension elements and vehicle operating parameters on the vibration distribution in a vehicle construction generated by the forces acting on the wheel

One of the main source of vehicle vibration is vertical movement of the wheel. It is caused by driving on road roughness. The excitation can be considered as time functions of the wheel strokes. It causes force transfer and dynamics response to the vehicle construction.

One may think of numerous systems and components of a vehicle which purpose is to absorb vibrations or minimise their impact. A vehicle suspension system, which consists of damping, springing and steering elements, are responsible to a considerable extent for damping of vibrations generated by road irregularities [28, 36, 38, 54, 55, 37, 134, 139]. Rubber components which provide mounting to such systems as engine, gearbox or exhaust system, also bear a fair share of responsibility for absorption of the vibrations generated by these assemblies. The purpose of every shock absorbing system and element is to minimise the impact exerted by vibrations on other systems as well as on the persons inside the vehicle. Oscillatory waves propagate and influence people via the vehicle structure, i.e. the frame or the body. Changes in the structure and composition of material may affect its capacity for the oscillatory wave propagation [153]. General vibrations are mainly transferred on men via lower extremities as well as the middle and lower section of the spine. The growing use of vehicles in urban areas causes that comfort in low-speed driving phase is an increasingly important consideration for manufacturers. The main sources of constraints in the occupant's environment are vibrations and sounds transmitted to the cabin via floor pan, dashboard, seats and steering wheels [7, 64].

6.1. 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 research comprised a series of active diagnostic experiments conducted in passenger cars. A car prepared to the tests, with the suspension components mounted having their technical condition known and their operating parameters preset, was subject to oscillatory input functions. For that purpose, a station enabling kinematic vibration excitation was used, making it possible to programme the dynamic frequency structure of input functions. The input frequency range envisaged comprised resonance frequency bands of both sprung and unsprung masses. Each time the test was conducted, a wheel of one vehicle axle was subject to the input function. The vibration accelerations were recorded at the chosen points of the structure (Fig. 6.1). For the sake of analysis of the suspension system damping parameters, vertical vibrations of unsprung elements (suspension arm) and the vehicle body (upper shock absorber mounting) were recorded coaxially. In order to analyse the distribution of vibrations being the sources of general vibration exposure of passengers, vibrations of the floor panel were recorded at locations where passengers rested their feet on the floor. These were also the points where general vibrations penetrated the human organism sitting inside the vehicle.

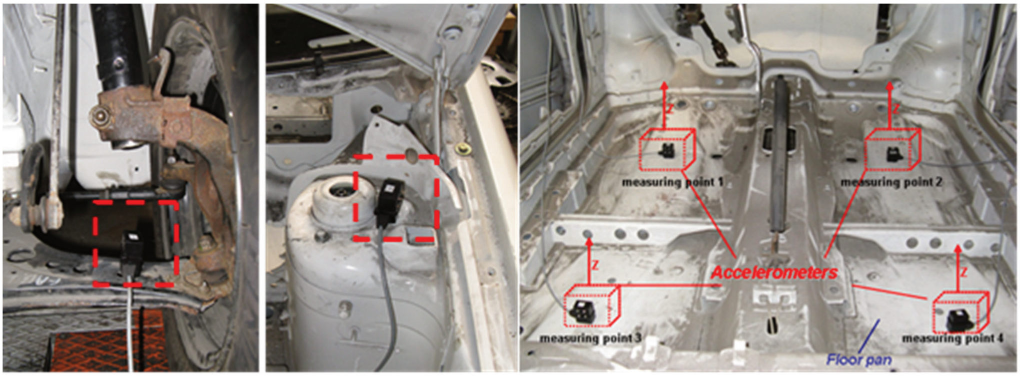


Fig. 6.1. Arrangement of vibration sensors across the structure of the vehicle tested

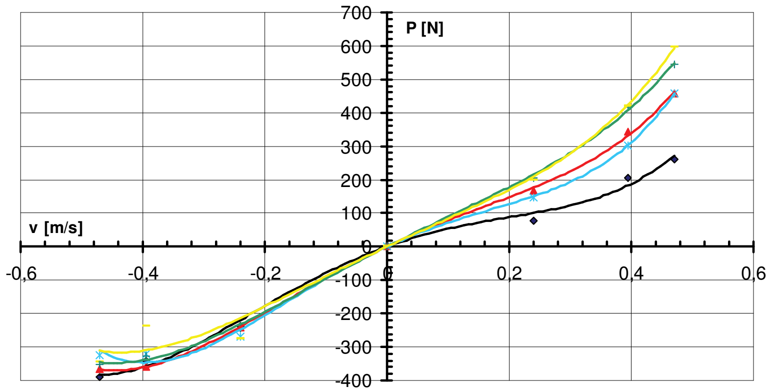


Fig. 6.2. Chosen applied damping characteristics of hydraulic shock-absorber: black – damping characteristics corresponding to the shock absorber with 60 % of fluid volume, red – 70 % of fluid volume, blue – 80 % of fluid volume, green – 90 % of fluid volume, yellow – 100 % of fluid volume

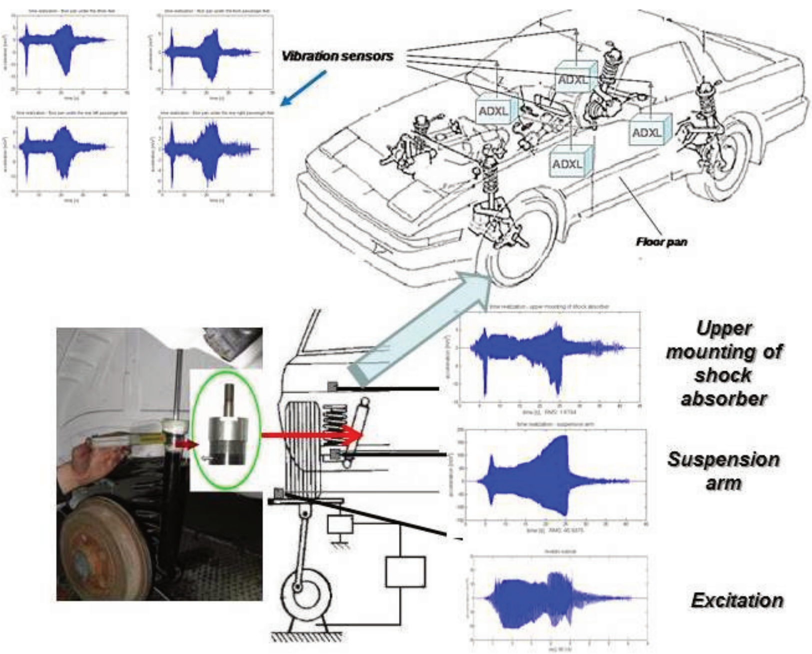


Fig. 6.3. Scheme of the experimental research

For the sake of investigation the research on different technical condition of chosen suspension elements and operating parameters of vehicle were conducted. The analysis of the mechanical system dynamics requires conducting research with vibration excitation system. It enables forcing of the tested system with the excitation programmed for the chosen frequency bands. One of the assumption of the research method was guarantee of the force excitation recurrence with possibilities of changing of the technical parameters of the researched vehicle.

6.1.1. Research on the impact of damping of shock absorbers on vehicle vibration

The first investigation was conducted on main element of the suspension to minimize vibration transfer from wheel to car-body. This element is the shock absorber. It was assumed that the main factor of the vibration damping element's technical condition was the degree to which the shock absorber cylinder was filled with shock absorbing fluid. The author has conducted many of research on different damping parameters of vehicles as force-speed characteristics of shock absorbers [56]. Some of the results of damping characteristics of shock absorbers with different volume of fluid are shown in Fig. 6.2.

The scheme of the research and process of shock absorber filling with working medium is presented in Fig. 6.3.

6.1.2. Research on the impact of the technical condition of springing elements on vehicle vibration

The scope of the research contained the tests of the impact exerted by changes in the technical condition of a front suspension coil spring. A schematic representation of the suspension system of the vehicle tested with the subject of the research and the vibration recording points marked are presented in the Fig. 6.4.

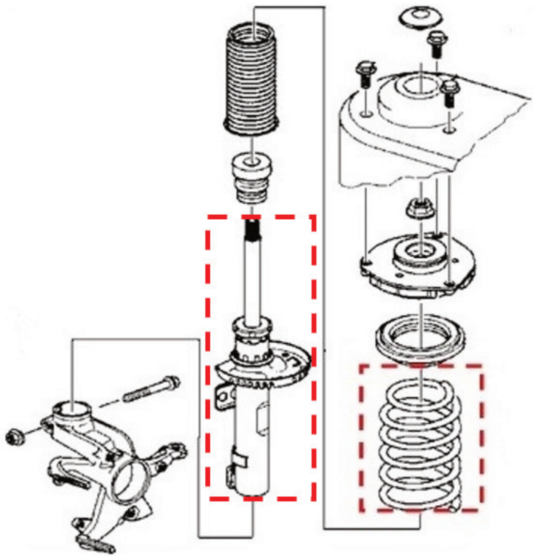


Fig. 6.4. Diagram of the front suspension system with marked objects of investigation

The identification of technical condition of suspension spring caused by defects (break) can be evaluated by the observation. The properties of coil springs are changing due to the operation period. It was assumed that the main factor of the vibration transfer related into spring is time and condition of operating in vehicle suspension. The experiments were conducted on passenger car with build in new and used (worn-out) suspension spring. The force vs. deflection characteristics of researching coil springs are presented in Fig. 6.5.

6.1.3. Research on the impact of the vehicle operating parameters on the vibration distribution

The technical condition of suspension elements is extremely important for vehicle vibration. But there are some other factors impacted on vibration in car construction. Technical condition of the vehicle systems have to be tested periodically during the vehicle control in the service station. It has to be confirmed by the authorized car diagnostician. It doesn't relieve the vehicle's owners or users from obligatory car control and maintain the recommended values of operating parameters, as i.e. tire type and pressure. The scope of the research contained investigation on influence of pressure in tires and extra load, as operating parameters, on the vibration distribution in vehicle structure.

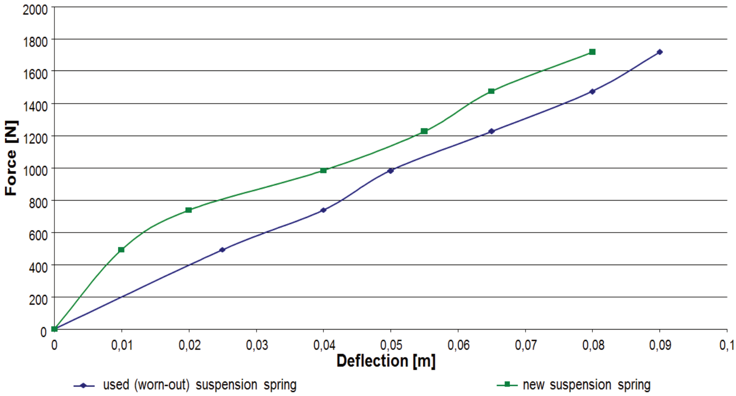


Fig. 6.5. Force vs. deflection characteristics of coil springs applied during research

6.2. Distribution of vibration in vehicle structure for different technical conditions of suspension elements and operating parameters of the car

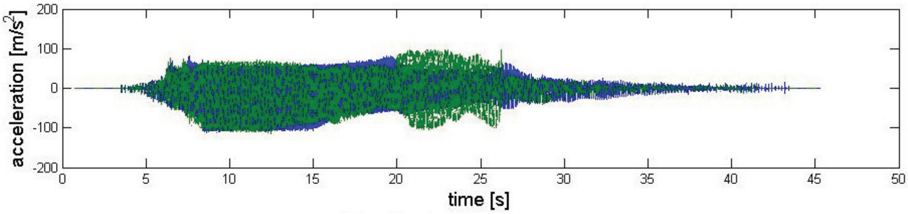
Due to the scope of the research the vibration signals in chosen location in the vehicle structure were registered. Thus the analysis of vibration distribution in vehicle construction can be analysed. For the purpose of identification of the parameters are impacted on vibration transferred to car body from vertical movement of vehicle wheels some active diagnostics experiments were planned.

6.2.1. Impact of the damping of shock absorber on distribution of vibration in vehicle structure

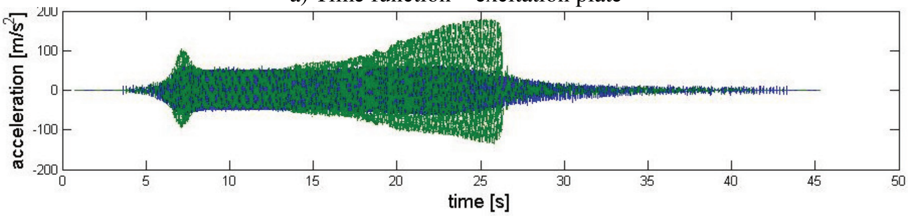
Under study the volume of the shock absorber liquid have been changed and as the results the different damping characteristics of the suspension, presented in Fig. 6.2, were applied. The comparison of the vibration registered in chosen location in the vehicle structure with build in shock absorber with 100 % and 50 % of liquid volume are shown in Figs. 6.6 and 6.7.

For the sake of preliminary analysis of the influence of the investigated parameters on level of vibration occurring in vehicle structure the resonance windows were identified. According to mechanical vibration theory the impact of mechanical system properties on generation and propagation of vibration is significant during resonance frequencies passing. Therefore comparison of resonance window of vibration signal registered under studying of vehicle with shock absorbers with 50 % and 100 % of volume of liquid are shown in Fig. 6.8.

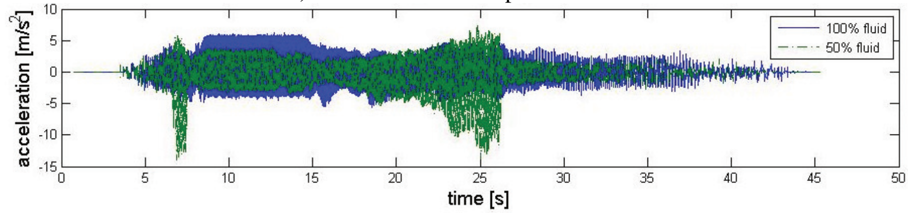
The preliminary evaluation of the influence can be conducted basing on simple global estimators, as RMS of total recorded signal and maximum value of the vibration acceleration in resonance window or maximum value of the absolute vibration acceleration in resonance window. The distribution of those estimators of 2 passenger cars vibration are presented in Figs. 6.9-6.11.



a) Time function – excitation plate

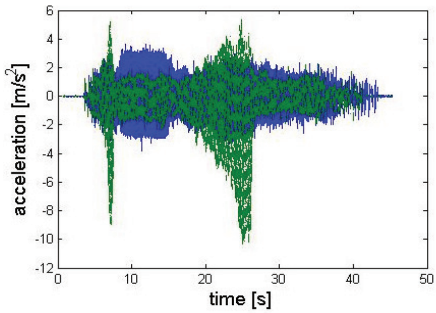


b) Time function – suspension arm

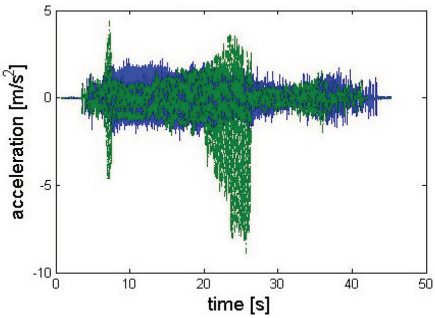


c) Time function – upper mounting of shock absorber

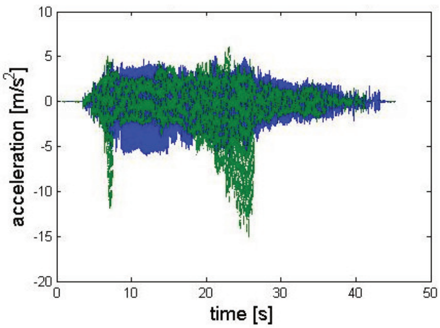
Fig. 6.6. Comparison in the vibration of exciter and suspension for the vehicles with build in shock absorbers with 100 % (blue) and 50 % (green) of liquid volume



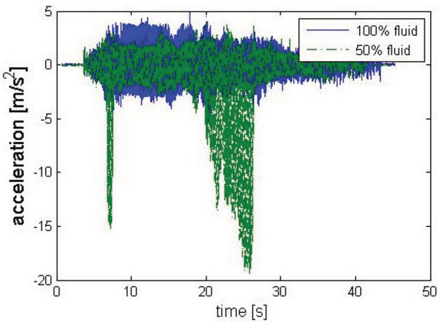
a) Time function – floor pan under the driver feet



b) Time function – floor pan under the front passenger feet

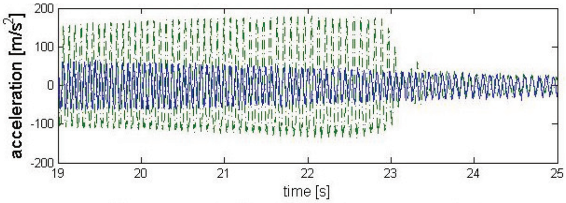


c) Time function – floor pan under the rear left passenger feet

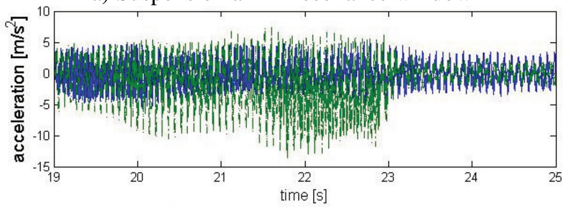


d) Time function – floor pan under the rear right passenger feet

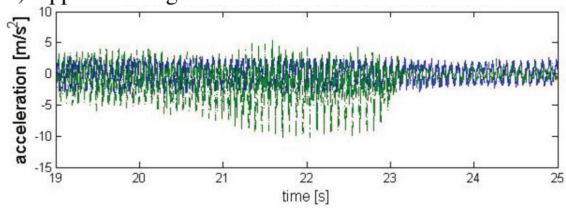
Fig. 6.7. Comparison in the vibration of floor pan for the vehicles with build in shock absorbers with 100 % (blue) and 50 % (green) of liquid volume



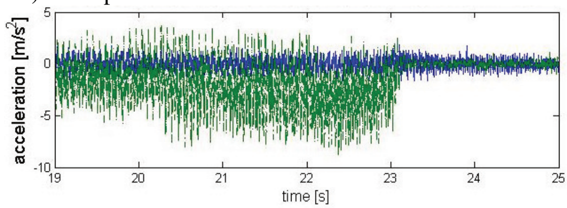
a) Suspension arm – resonance window



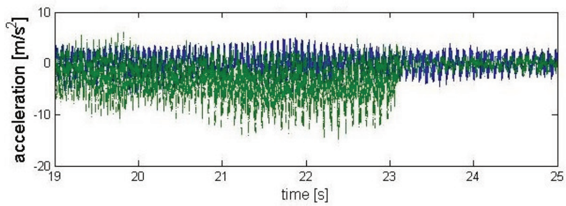
b) Upper mountig of shock absorber – resonance window



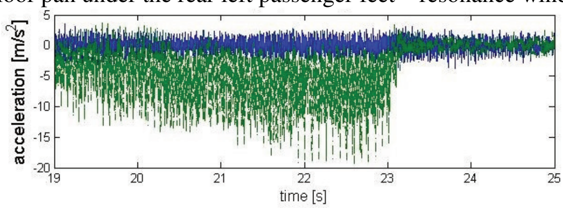
c) Floor pan under the driver feet – resonance window



d) Floor pan under the front passenger feet



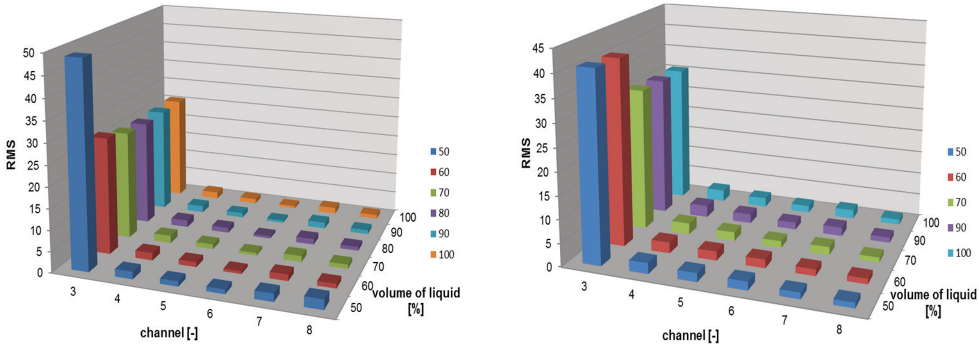
e) Floor pan under the rear left passenger feet – resonance window



f) Floor pan under the rear right passenger feet – resonance window

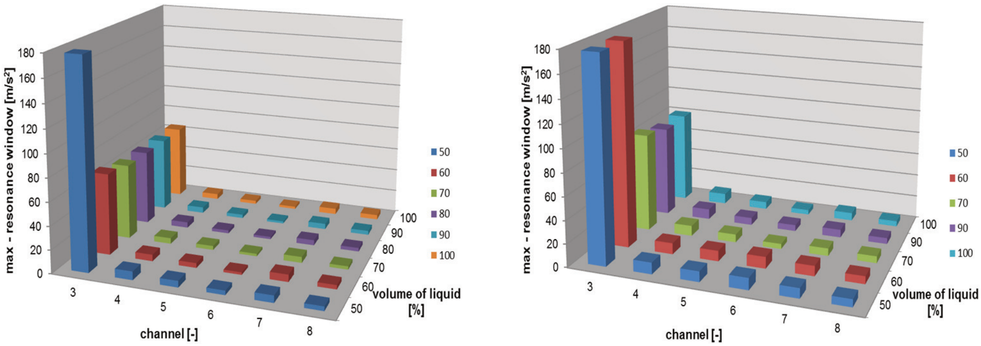
Fig. 6.8. Comparison of resonance windows of vibration signal for the vehicles construction with build in shock absorbers with 100 % (blue) and 50 % (green) of liquid volume

The acceleration of vibration have been acquired by the channels: 2 – vibration exciter plate, 3 – suspension arm, 4 – upper mounting of shock absorber, 5 – floor under driver's feet, 6 – floor under front passenger's feet, 7 – floor under rear left passenger's feet, 8 – floor under rear right passenger's feet.



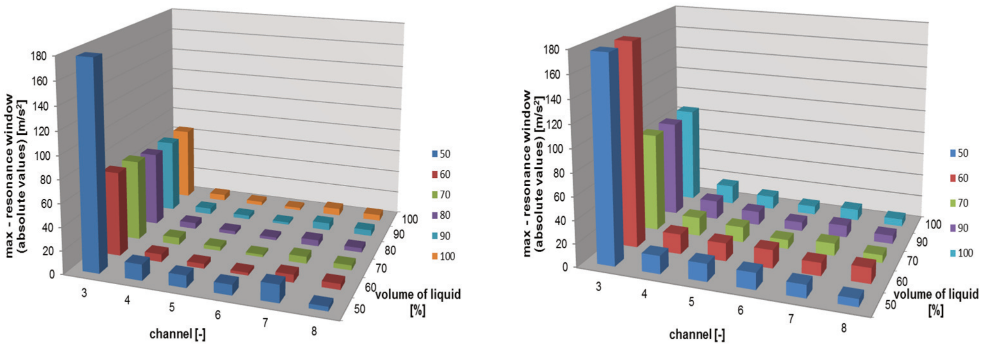
a) b)

Figs. 6.9. Distribution of changes in the RMS values of vibration acceleration signal for a variable damping properties of shock absorber: a) Skoda Fabia, b) Fiat Punto



a) b)

Figs. 6.10. Distribution of changes in the maximum values of vibration accelerations in resonance window for a variable damping properties of shock absorber: a) Skoda Fabia, b) Fiat Punto



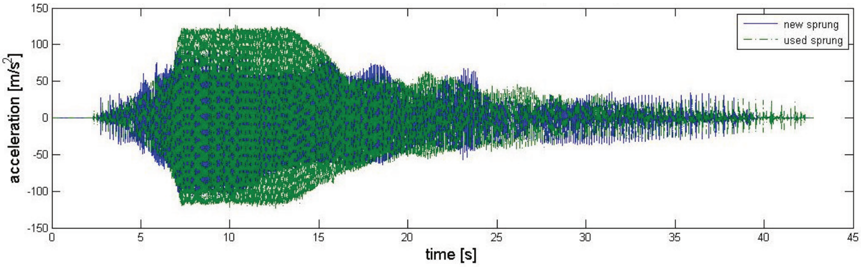
a) b)

Figs. 6.11. Distribution of changes in the maximum of absolute values of vibration accelerations in resonance window for a variable damping properties of shock absorber: a) Skoda Fabia, b) Fiat Punto

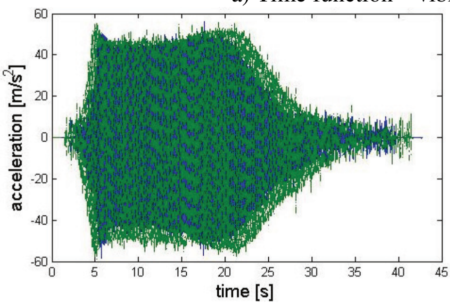
6.2.2. Impact of the suspension spring properties on distribution of vibration in vehicle structure

The coil springs with different characteristics, presented in Fig. 6.5, were applied into suspension of the vehicle. The comparison of the results obtained are shown in Figs. 6.12 and 6.13.

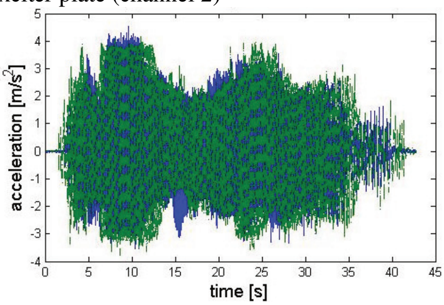
The properties of the spring is correlated to the suspension stiffness. It depends on many parameters and one of them is load of the vehicle. Thus the scope of the research contain investigation on different value of the vehicle's extra load.



a) Time function – vibration exciter plate (channel 2)

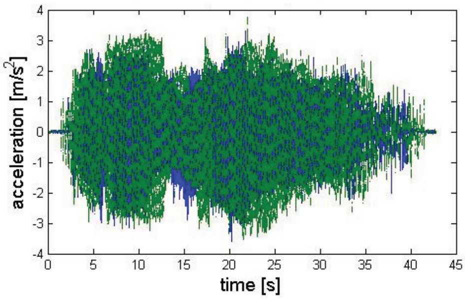


b) Time function – suspension arm (channel 3)

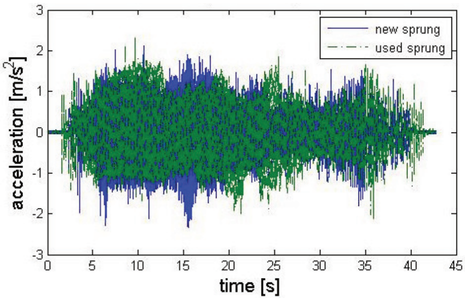


c) Time function – upper mounting of shock absorber (channel 4)

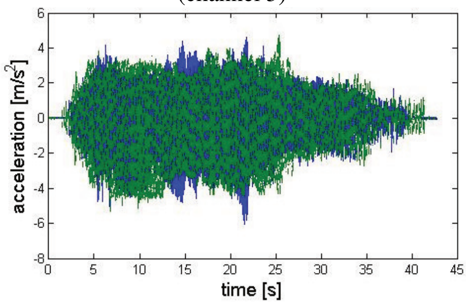
Fig. 6.12. Comparison in the vibration of exciter and suspension for the vehicles with build in new and used (worn-out) suspension spring



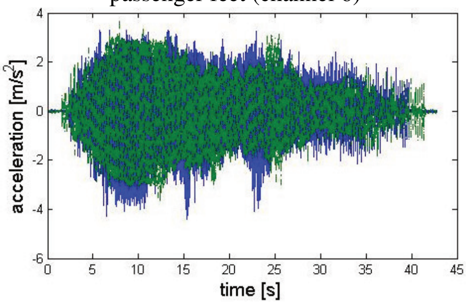
a) Time function – floor pan under the driver feet (channel 5)



b) Time function – floor pan under the front passenger feet (channel 6)



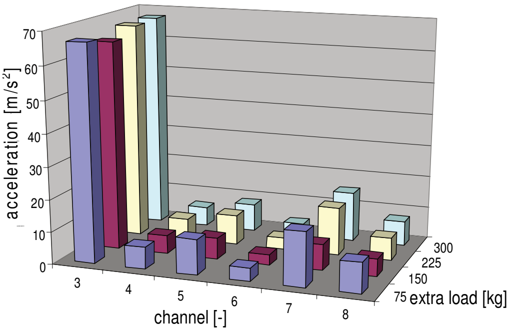
c) Time function – floor pan under the rear left passenger feet (channel 7)



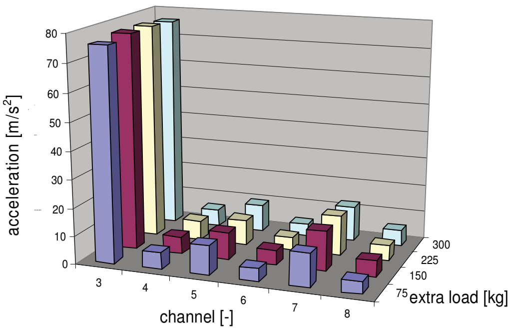
d) Time function – floor pan under the rear right passenger feet (channel 8)

Fig. 6.13. Comparison in the vibration of floor pan for the vehicles with build in new and used (worn-out) suspension spring

The distribution of the maximum value of the vibration acceleration in resonance window is presented. The distribution of those estimators of vehicle’s vibration with build in new and used (worn-out) spring is presented in Fig. 6.14.



a)

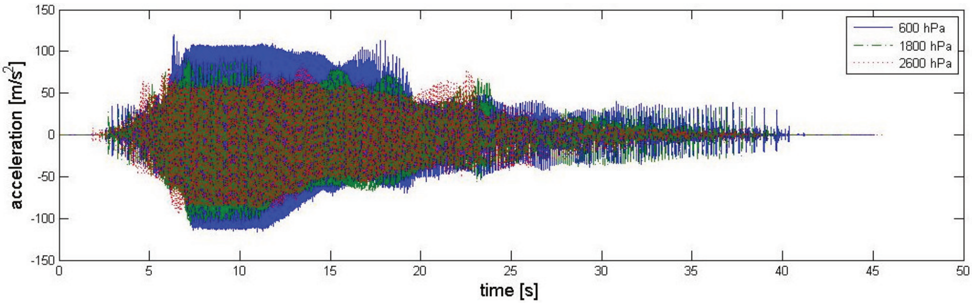


b)

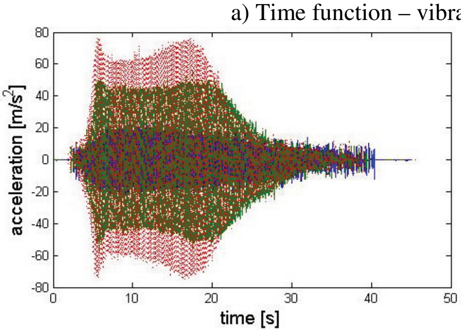
Fig. 6.14. Distribution of changes in the maximum values of vibration accelerations in resonance window for a vehicle with build in a) new and b) used (worn-out) spring

6.2.3. Impact of the pressure in tires on distribution of vibration in vehicle structure

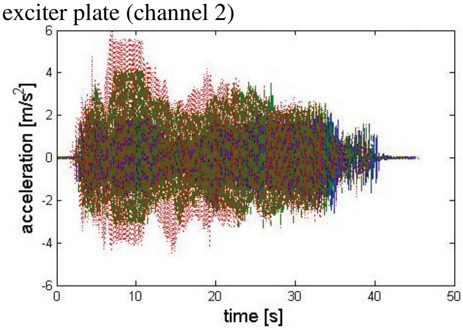
The scope of the research contain investigation of the vehicle operating parameters impact on the vibration distribution. During the research the pressure in tires and extra load were chosen as operating parameters. These parameters have significant influence on damping and stiffness properties of the vehicle suspension. It was assumed to conduct the investigation on complex factors of suspension stiffness properties, as combination of different values of tire pressure, extra load and coil spring properties. The comparison of the obtained results are shown in Figs. 6.15 and 6.16.



a) Time function – vibration exciter plate (channel 2)



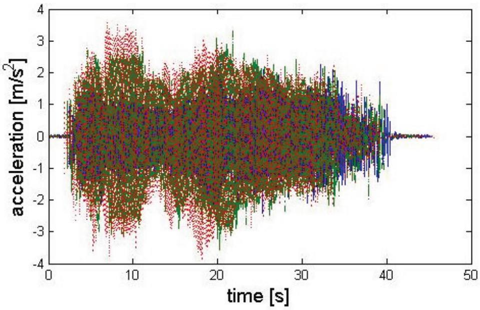
b) Time function – suspension arm (channel 3)



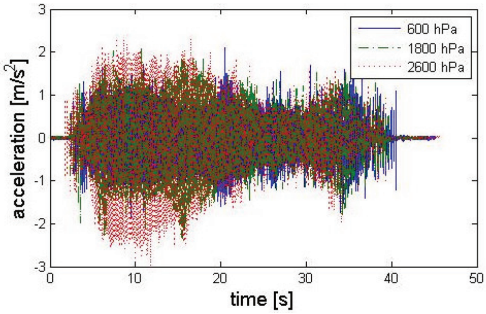
c) Time function – upper mounting of shock absorber (channel 4)

Fig. 6.15. Comparison in the vibration of exciter and suspension for the vehicles with different presure in tires (600 hPA, 1800 hPa, 2600 hPA)

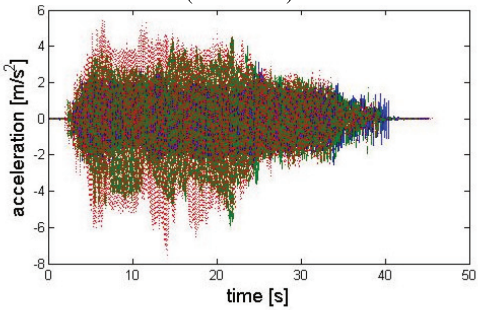
The distribution of the vibration acceleration maximum values in resonance window is presented. Fig. 6.17 present the distribution of those estimators of vehicle‘s vibration with different pressure in tires with build in new and used (worn-out) spring.



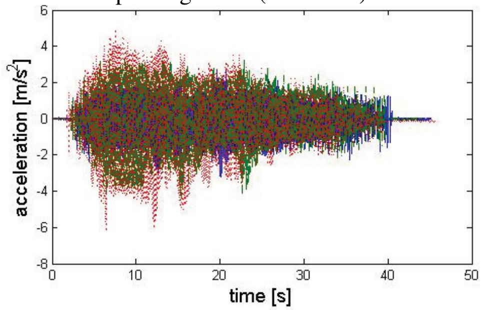
a) Time function – floor pan under the driver feet (channel 5)



b) Time function – floor pan under the front passenger feet (channel 6)

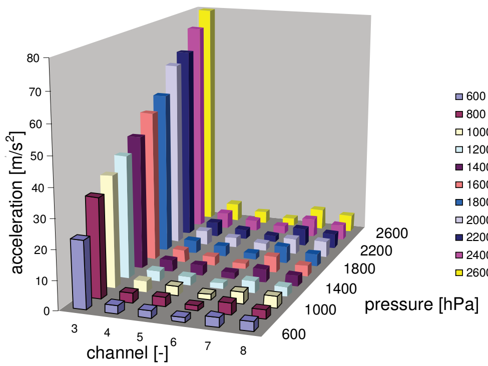


c) Time function – floor pan under the rear left passenger feet (channel 7)

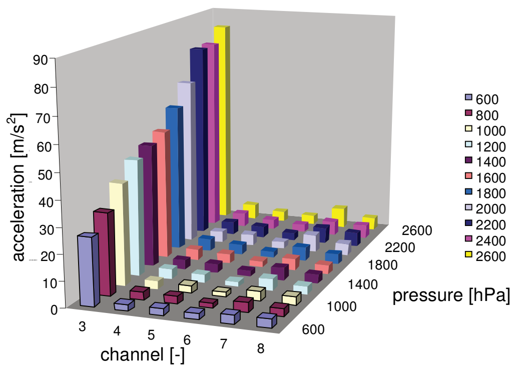


d) Time function – floor pan under the rear right passenger feet (channel 8)

Fig. 6.16. Comparison in the vibration of floor pan for the vehicles with different presure in tires (600 hPA, 1800 hPa, 2600 hPA)



a)



b)

Fig. 6.17. Distribution of changes in the maximum values of vibration accelerations in resonance window for a vehicle with different pressure in tires with build in a) new and b) used (worn-out) spring

6.3. Discussion on impact of suspension components and operating parameters of a vehicle on the propagation of vibrations

Studies of the impact exerted by the technical condition of suspension components and the chosen operating parameters of a vehicle on the propagation of vibrations generated by a road wheel vertical motion to the vehicle structure are particularly important in cognitive terms for the analysis and identification of the vibration sources and propagation in vehicles. The purpose of those studies was to identify factors affecting the propagation of vibrations caused by the dynamic impact of road irregularities on wheels of a moving vehicle.

Due to the fact that the technical condition of a decided majority of cars using roads is far from being normative, the vibration propagation studies were conducted for various technical conditions of suspension components as well as the vehicle operating parameters. For the sake of the preliminary assessment of the impact of the cases studied on the vibration propagation, courses of the vibration accelerations being recorded were compared and global measures of signals were determined and collated as maximum values, RMS values and maximum values in resonant windows.

For each case analysed, the impact of vibration propagation in a vehicle was established. The smallest impact was observed for the operating parameter of the additional vehicle load, which results from the car designers being well aware of the problem in question. As regards other factors, such as the vibration damping characteristics of shock absorbers (degree of filling with shock absorbing fluid), rigidity characteristics of a helical spring (determined by comparing a new and a used one) and tyre pressure, changes to these factors considerably affected the vibrations recorded at selected points of the vehicle structure. The recording results obtained proved the highest susceptibility to vibrations propagated through the vehicle structure for variable tire pressure, observed even on small changes. A significant impact was also exerted by a change in the vibration damping characteristics of a shock absorber, however, it was practically only experienced after exceeding the level of 60 % corresponding to the absorber cylinder filling with shock absorbing fluid, and that is to be considered as considerable leakage. Furthermore, being analysed in such a manner, the results obtained have enabled assessment of the vehicle suspension damping properties by comparing the vibration values recorded at the suspension arm, being un unsprung element, and axially measured at the arm's upper mounting point, being a sprung element, as well as on the vehicle floor panel, comprising points of impact of the vehicle body induced vibrations on organisms of passengers.